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FOREST NURSERY AND PLANTING PRACTICE IN THE CALIFORNIA PINE REGION

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THE PLANTING PROBLEM IN THE PINE REGION

The area of once forested lands requiring planting in the California pine region[1] is very large. Estimates ranging from 300,000 to 2,000,000 acres, though obviously very crude, serve at least to emphasize the magnitude of the planting job. On a large part of these lands all timber growth has been swept away by repeated fires and no chance for natural reproduction remains. For the rest, lumbering followed by fire (*4*)[2] and in recent years lumbering alone, have denuded the land quite as thoroughly. Planting with native conifers is the only known possibility of making these areas again productive within several generations.

Planting is tremendously complicated, however, by the fact that this denuded land has been captured by a dense stand of brush (*5*).

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[1] The California pine region contains the forests of western yellow pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), Douglas fir (*Pseudotsuga taxifolia*), white fir (*Abies concolor*), and incense cedar (*Libocedrus decurrens*), that grow on both the east and west slopes of the Sierra Nevada and the Coast Range, on the cross ranges of northwestern California, and on the broad plateaus of the northeastern part of the State. Of the 16,000,000 acres of forest land in this region, 2,000,000 acres is denuded of commercial timber and now bears only worthless brush or brush and scattered trees. At low elevations are broad belts of chaparral land totaling 1,000,000 acres, on which little evidence of timber growth exists. Of the remainder 12,000,000 acres is in virgin timber and 1,000,000 acres is productive cut-over land. The significant feature is that current logging and fire are increasing the unproductive areas each year, at the cost of the productive land.

[2] Reference is made by italic numbers in parentheses to "Literature cited," p. 74.

Because of the rapidity with which brush fields[3] form, it is only on lands that are planted within a few years after the forest is destroyed that the task is easy. Brush-field planting is the outstanding problem in the region; planting on more recently denuded lands is of secondary though increasing importance.

With so great a job of planting in prospect, efforts must be concentrated on the areas where reforestation is most urgently needed and will be most effective. For those brush fields where seed trees have to any degree survived past fires, natural restocking must be depended on, for the present at least, even though seedlings will come in very slowly. On lands now occupied by chaparral,[4] where fire has destroyed the organic material in the soil and erosion has seriously reduced the depth of the soil, no immediate means is available to restore forest growth. On such lands a process of soil building, with fire exclusion a prime feature, must be gone through before the native conifers can again exist. If planting is tried experimentally on chaparral lands hardwoods should first be used for their value as soil builders.

It is necessary also to exclude from the immediate problem of planting such projects as the filling in of blanks in forests partially cut out, even where natural reproduction is coming in very slowly. The acreage far more urgently requiring planting is too large, and, because of current cutting methods on private lands, is increasing too rapidly, to justify planting any areas where possibility of natural reproduction still exists. On such areas both the Federal Government and those private owners intent on growing timber will probably rely on natural reproduction to the greatest possible degree.

The importance of restocking the brush fields was recognized early in the national-forest administration. The first attempt, based on an inadequate conception of the difficulties, and recognizing the urgent need for inexpensive and large-scale operations, was naturally by direct seeding. From 1908 till 1913 seed of the important native conifers was sown in scores of brush fields.

In these first attempts rodents destroyed the greater part of the seed, whether fall or spring sown. Later efforts, which included poisoning of the seed coat itself and destruction of rodents by poisoning and trapping on the area to be seeded, proved utterly ineffective in reducing the rodent population, and screening the seed spots, which was also tried, though effective, was too expensive for any but experimental purposes. In the rare cases where the unscreened seed escaped destruction and germinated, heavy losses during the summer drought eliminated nearly all the seedlings.

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[3] The term brush field, as here used, denotes the temporary associations of shrubs and sprouts of hardwood trees which universally capture land within the commercial timber belt on which the forest has been largely or wholly destroyed. The number of shrubby species occurring in the brush fields is well over 100, and the mixture of species varies greatly in different parts of the region and on different sites. Among the most widespread and abundantly represented are sprouts of California black oak (*Quercus kelloggii*), and bushes of huckleberry oak (*Q. chrysolepis vaccinifolia*), common manzanita (*Arctostaphylos patula*), golden chinquapin (*Castanopsis chrysophylla*), bluebrush (*Ceanothus integerrimus*), whitethorn (*C. cordulatus*), snowbrush (*C. velutinus*), wild plum or Pacific plum (*Prunus subcordata*), western chokecherry (*P. virginiana demissa*), and serviceberry (*Amelanchier alnifolia*). Height of brush varies in general from 3 to 8 feet, and the fields are ordinarily very dense and difficult to travel in.

[4] Chaparral is a general term for shrubby growth on land on which little or no evidence exists that commercial forests once grew there. In part the chaparral lands include a foothill belt where even with deep soils the commercially important California conifers can not grow because of deficient rainfall or excessive heat. In part they include steep slopes, probably once forested, but where erosion following fires has resulted in serious deterioration of the soil in depth and in quality. Some of the more common and widespread species of shrubs characteristic of chaparral are chamise (*Adenostoma fasciculatum*), wedgeleaf (*Ceanothus cuneatus*), manzanita (*Arctostaphylos* sp.), California scrub and highland live oaks (*Quercus dumosa* and *Q. wislizenii*), and toyon (*Heteromeles arbutifolia*). As in the brush fields, a large number of other species also occur, and the height and density of brush is similar to that in brush fields. In the contact zone where typical brush fields merge into typical chaparral areas there is naturally some intermingling of the species characteristic of each type.

Various methods of sowing the seed were employed. Prepared spots were used with the seed covered, the seed was broadcasted on the ground or snow, and attempts were made with the corn planter. Under all these methods the seeds were destroyed by rodents or the seedlings by drought.

The net result of the direct-seeding campaign was almost universal failure. In a few very favorable spots Jeffrey pine (*Pinus jeffreyi*) was partly successful, but even there the stands were scattered and irregular. By 1911 it began to be evident that direct seeding could not be used with success, and it was then that the development of nursery and planting practice began.

At first it appeared that the essential was simply to raise the trees and set them in the field. No great technical difficulties were anticipated. But the first planting experiments made in 1911 dispelled the illusion, for serious obstacles were encountered in nursery practice and in field losses from rodents, drought, and improper planting. Thus by 1913 it became clearly recognized that before extensive plantings could be made with assurance of success systematic and detailed research would be required.

The establishment in 1913 of a forest experiment station at Feather River[5] offered the opportunity to undertake such a program. At the same time administrative planting was continued on the Shasta National Forest, whereby the results of research were tested and certain phases of brush-field planting were studied independently.

Thus the work of the period from 1908–1920 went through the stages of direct seeding, of planting without an adequate basis of research, and finally entered upon planting primarily for the determination of technic. The initial and even later failures, as well as the difficulties yet to be solved, by no means prove that planting is an impossible task. Planting can be done successfully on all potential timberlands. Experience in many countries shows that problems in reforestation and afforestation that have at first appeared insolvable have been solved.

The primary purpose of this circular is to make available what has been learned to date about planting in this region, the difficulties involved, the technic necessary for success, and the degree of success possible. Success in planting depends on attention to a multitude of details, in raising the stock in the nursery, in selecting sites, and in the actual conduct of planting. These are the first things to learn. Afterwards it is time to develop methods and practices for large-scale operations, reduction of costs, and planting reconnaissance, and to attend to similar questions. Therefore discussion of the latter will be omitted, as will the mechanics of nursery work, which has been adequately treated by others (*6*, *7*, *8*).

The experimental nursery and planting work in northern California has aimed to solve, for the six important native conifers—

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[5] Now a branch station of the California Forest Experiment Station.

western yellow, Jeffrey, and sugar pines, Douglas fir, white fir, and incense cedar—the technical methods required to produce stock capable of surviving the trying field conditions characteristic of the region. The Feather River station has been the scene of most of the intensive experimental work. This station is located in Plumas County in north-central California, latitude 40°, at an elevation of 3,500 feet, on the west slope of the Sierra Nevada, well within the western yellow pine timber type and yet within a short distance of other important types, such as the western yellow pine–sugar pine, and sugar pine–white fir. The more extensive experiments have centered at and near the Pilgrim Creek nursery on the Shasta National Forest in Siskiyou County. This station is at an altitude of 4,000 feet in the pure western yellow pine type of the east slope of the Sierras, latitude 41° 40′. At Feather River the soils are clays and clay loams; at Pilgrim Creek they are the "lava ash" typical of the east slope of the Sierras. The two stations are typical of large areas in the California pine region.

PHYSICAL CONDITIONS MET IN PLANTING

MOISTURE RELATIONS

Of all the factors which influence what can and can not be done in reforestation, certainly none is more dominant than climate, particularly moisture. A strongly marked dry summer is characteristic of northern California. This coupled with the high temperatures, makes the establishment of forest stands unusually difficult.

RAINFALL

In Table 1 are summarized the essential data on seasonal precipitation for Mount Shasta, Calif., located at the approximate elevation and within a few miles of one of the principal experimental planting areas. These data illustrate strikingly the dryness of most of the growing season and the great variability of individual seasons, both in amount and distribution of precipitation. In one year (1916) there was not a single month with as much as 1 inch of rain during the entire growing season (April to October); in 1915 and 1917 there were but two months with over half an inch; in 1916 the total seasonal precipitation fell to as low as 38 per cent of normal, only 2.58 inches, for 7 months. On the other hand, 1912 had precipitation of at least a half inch in 6 out of 7 months, and over 1 inch in 4 out of 7 months. On the average the 4 months of June to September, inclusive, each have less than 1 inch of rain. The mean annual precipitation for this station is about 40 inches.

SOIL MOISTURE

That this great variation in precipitation affects tree establishment largely through the medium of soil moisture is obvious. Figure 1 gives an interesting contrast in the characteristic soil-moisture curves for dry and wet years. The data were taken in open ground at Feather River, where precipitation was strikingly similar, both in amount and distribution, to that recorded for Mount Shasta. In a dry year, such as 1916, the soil moisture drops rapidly in spring, going below 5 per cent by the middle of July and remaining below that level until nearly the end of September. In a wet year soil moisture drops more slowly, remains above the danger line of 5 per cent throughout the summer, and rises again somewhat earlier in the fall than in a dry year. In a region with dry summer climate relatively small changes in critical physical factors cause profound changes in survival of forest trees during the period of establishment. A variation of a small percentage in soil moisture may well make the difference between success or failure of plantations, and points to the intrinsic difficulty of the planting problem in dry-climate silviculture.

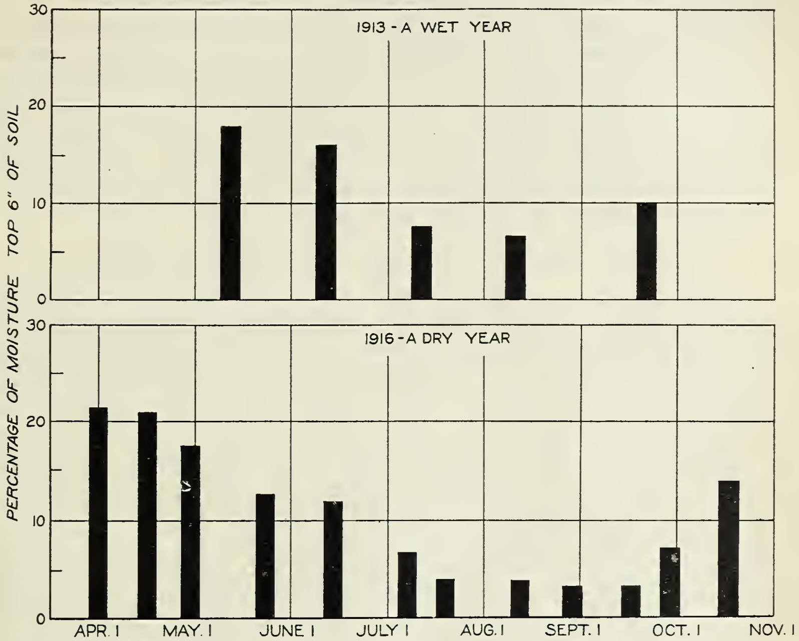

FIGURE 1.—Moisture content of top 6 inches of soil during typical wet and dry years, Feather River, Calif.

TABLE 1.—*Average precipitation for summer months (1911–1920) typical of Pilgrim Creek planting area in northern California* [1]

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Total		Months with at least—	
										½ inch	1 inch
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Rainy days*	*No.*	*No.*
1911	2.02	1.60	0.31	0.72	0.00	1.01	0.58	6.24	25	5	3
1912	4.13	2.20	.90	.48	.56	3.12	1.77	13.16	38	6	4
1913	2.55	2.38	2.20	.55	.38	.17	.60	8.83	22	5	3
1914	1.70	1.48	1.12	.42	.00	.61	2.00	7.33	26	5	4
1915	1.62	3.97	.04	.14	.00	.00	.10	5.87	16	2	2
1916	.06	.54	.62	.20	.76	.00	.40	2.58	14	3	0
1917	2.15	.75	.00	.00	.21	.38	.00	3.49	12	2	1
1918	1.30	.36	.00	.00	.20	3.76	2.73	8.35	27	3	3
1919	1.13	.20	.20	.00	.00	1.26	.13	2.92	14	2	2
1920	4.35	.50	.95	.60	.55	.35	2.05	9.35	24	6	2
Average	2.10	1.40	.63	.31	.26	1.07	1.04	6.81	22	3.9	2.4

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[1] The records are those of the U. S. Weather Bureau from the Mount Shasta (formerly Sisson) station, a few miles distant from the planting area.

EVAPORATION

Evaporation is recognized as one of the major climatic influences, although in this country comparatively little work has thus far been done in measuring it. Livingston and Shreve (*1*), on the basis of a 1-year study, concluded that desert conditions are marked by weekly evaporation of over 300 cubic centimeters, as measured by the porous-cup atmometer, and that 200 to 300 cubic centimeters may be expected for the growing season in northern California forests, with an average of 250 cubic centimeters. A series of evaporation determinations with the same instrument at Feather River in 1918 gave a weekly average of 375 cubic centimeters for June, July, and August, with a total precipitation for the same period of 0.2 inch. These data, though by no means final, confirm the severity of the growing season climate, particularly in unfavorable years.

CLIMATIC SEVERITY DEMANDS HIGH-QUALITY STOCK

With the moisture relations obtaining in the northern California timber region at best but moderately favorable during the growing season, and at worst extremely critical, it should be obvious not only that natural reproduction is not dependable, but that success in planting will require the greatest care. The basic consideration in the development of nursery and planting technic must be that only high-quality stock carefully planted can succeed consistently. Unfavorable years appear to be at least as frequent as good years, and general practice should therefore be designed to meet the average worst conditions that experience shows must be expected.

Climatic conditions are the overwhelmingly dominant consideration in the development of nursery and planting practice in any region. The most conspicuous failures have been due either to failure to gage correctly the difficulties to be overcome or to a false idea of the ease of planting based on success in one or two favorable seasons.

BRUSH COVER

The problem of planting is further complicated by the almost universal occurrence on lands formerly forested of dense stands of brush that make any planting operation extremely difficult under the best climatic conditions. Travel through these brush fields can be accomplished only with much labor, digging of holes for the young trees is seriously impeded, and the heavy layer of leaves and twigs on the ground makes it hard to obtain clean mineral soil to fill in the holes. Furthermore, the brush competes with the planted stock for the limited available soil moisture and is able to satisfy its demands more readily.

On an area where the brush had recently been killed back by fire, soil moisture was found to be 12.3 per cent in September, whereas on an otherwise similar dense brush area it was only 7.2 per cent. This significant difference emphasizes the difficulty of planting in competition with established vegetation. No means are now available for eradicating brush in advance of planting. Killing back by fire is a temporary but very useful aid in the planting operation and in initial survival of the trees. Broadcast burning of brush fields, though attended with some danger, is practicable if cleared lines surround the area and if an adequate crew is on hand to do the burning.

EXPERIMENTAL METHODS USED

IN NURSERY PRACTICE AND FIELD PLANTING

A description of the experimental methods may best be given at the outset, in order to avoid repetition. The methods employed in the nursery work at Feather River are those generally recognized as proper in experimentation, being designed to eliminate all but one variable in each series of tests. Many of the experiments were repeated to insure accuracy.

In the field planting at Feather River about 45,000 plants were observed for four to eight years after being set out in the field, and in addition many thousands more were used as samples during the course of the work. About 500 separate field tests were made, dealing with nearly every phase of nursery and planting technic.

On the Shasta National Forest some 25,000 individually numbered trees were observed for two to eight years, detailed notes concerning each plant being taken at each examination.

The basis of data may be considered adequate, and the periods of observation generally long enough to justify conclusions concerning initial survival, even though subsequent losses have occurred on some of the plots.

In nearly every test at Feather River the results of treatment in the nursery were finally checked by study of survival and behavior of the plants in the field. To insure uniformity of results, all planting was done by one man and plots were carefully selected to eliminate or at least minimize differences of site conditions. Most of the field plots consisted of parallel rows, rather than rectangles, in order to insure like conditions for the several component parts of the test. Generally 100 plants of each lot were planted and, except on a few plots, duplicate field tests were run, one being planted in the fall (October or November) and one in the spring (March or April).

The more extensive work carried on during the same period on the Shasta National Forest had a decidedly different technic.

From 1911 to 1921, field planting on the Shasta, attained an average of about 200 acres per year. During that period the results were followed closely by means of periodic examinations of representative samples from each plot. The method was to stake and number the individual plants in sample rows 5 or 10 chains apart, the rows running at right angles to the direction of the planting. In this way the same plants were examined each time and the work of all the planters in a crew was sampled, so that true averages could be obtained.

This form of examination is particularly adapted to the study of survival during the first 4 or 5 years after planting. Serious losses may occur later, as in plants established for 10 years on the Shasta National Forest, but so far the cause for such losses has not been isolated. On the Shasta, the prolonged drought lasting from 1916 to 1924 was probably the principal agency.

For each plant at each examination the following facts were recorded: Serial number, shade condition, ground cover, species of brush giving shade, condition of plant, and cause of injury or death of plants. Shade was classified as from 0, 1, 2, 3, or 4 sides, and full shade, or 4 sides and overhead; and ordinarily direction was also recorded by a simple system. Thus, the symbol ⊐ indicated shade from north, south, and east (3 sides); ∟ shade from west and south (2 sides), and □ shade from 4 sides.

Condition of the tree was determined as healthy, sickly, dying, or dead, the first and last terms being self-explanatory. Sickly plants are those which are off color or are injured, but which have an apparent chance to survive. Dying plants are those which in all probability have no such chance.

Four principal causes of death were recognized, namely, carelessness in handling, poor planting, drought, and mechanical injury, the last particularly by rodents. The first includes improper handling and packing at the nursery, drying out in the crate, and exposure during the planting operation. Plants subjected to severe mishandling may be dead, of course, when set out, even though the tops are still green. They are recognized later as dead from this cause, when there is no evidence of poor planting.

Poor planting may consist in setting plants too high or too low, with badly curled or doubled-over roots, with insufficient tamping of soil, or of filling in leaf mold or otherwise leaving air spaces around the roots. Poor planting can usually be detected by digging up the plants. Rodent damage is nearly always nipping of the top, though occasionally gophers or moles cut the roots. Drought damage appears in late summer and fall, and is simply the failure of the plant to become established. To this cause the less obvious poor planting is often a contributing factor. Rarely, other forms of damage appear, such as sliding earth or rock on steep slopes, trampling by cattle, and root cutting by larvæ of the May beetle, but these are unimportant in the aggregate.

A QUANTITATIVE STANDARD OF QUALITY

Early in the nursery and field-planting research it became obvious that a standard common denominator was essential by which to compare results of different methods of treatment. The results of field tests are clearly indispensable, but in comparing, for example, several different age classes, the percentages of plants alive do not tell the whole story and are often apparently contradictory. Why, for instance, should 1–1[6] western yellow pine show higher survival than 1–2 stock, when the latter is larger and apparently better developed? Or, why should 1–1 western yellow pine grown entirely without shade show higher survival than stock of the same age grown in the seedling beds under half shade, though the two lots are apparently identical in appearance and size?

The first thought of the investigator naturally is to get away from such general descriptive terms as "well balanced," "thrifty," and "first class," which rest on individual judgment and are qualitative rather than quantitative. Various possible criteria suggest themselves, such as lengths, weight, diameter of stem, and number and length of needles and of roots. Different investigators have used all of these. After some preliminary study and experiment, the most promising criteria were found to be the weight of top and roots (the ground line being taken as the dividing point) and the ratio between the two, or

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[6] As readers familiar with nursery practice will know, this terminology indicates the number of years spent by the plant in the seed bed and in the transplant bed. For example 1–1 stock are transplants 2 years old that have been one year in the seed bed and one year in the transplant bed. Similarly, 1–2 stock and 2–1 stock are both 3 years old, the former having been transplanted at 1 year of age, the latter at 2 years.

$$\frac{\text{weight top}}{\text{weight roots.}}$$

Only the weight of roots after pruning for field planting was used, and green weight rather than dry weight was determined for each lot of plants.

Considerable theoretical justification for such a standard may be adduced. Other things being equal, the greater the surface area (and weight) of the top, the greater the transpiration; and the greater the area (and weight) of the roots, the greater the absorption of moisture from the soil. So, given two plants with tops of the same weight, the one with heavier root system is able to absorb more moisture and hence under critical field conditions has a higher chance of survival.

During the course of the experiments this hypothesis has been tested in 239 lots of nursery stock, involving the six important tree species, many age classes, and 364 field tests. Without going into a detailed discussion of the results of these tests, two general statements can be made regarding the comparison of different lots or age classes of a given species:

(1) Of several groups of plants with equal or approximately equal ratios of tops and roots, that with the greatest weight will have the highest survival in the field, given of course, the same field conditions for all groups.

(2) Of several groups having roots of equal or approximately equal weight, that with the lowest ratio of weight of tops to roots will have the highest survival.

In this circular the weight and top-root ratio will be used as the standards in interpreting results of different methods of nursery treatment and in explaining results of field tests.

NURSERY PRACTICE

The following specific phases of nursery practice will be discussed: Use of seed-test values, soils, season of sowing, quantities to sow, depth of sowing, drill versus broadcast sowing, kind of mulch, shading, and watering and cultivation.

No attempt will be made to discuss such questions as labor-saving devices, crew organization, cost-keeping system, and large-scale production. Study of the technic of producing high-quality stock is the primary aim.

The general plan of presentation to be followed will be first a subdivision into the main phases enumerated, and under each a discussion of the experimental work for each of the principal species. In this way the differences and similarities of behavior of the species can best be demonstrated.

THE USE OF SEED-TEST VALUES

It is necessary to know the yield per pound of seed, in estimating both the quality of stock produced and the total crop of plants.

Seed is collected in the fall, and sown in the nursery at once or early in the following spring. Some preliminary estimates of germinability must be made, by cutting or greenhouse tests, and the probable relation of these to germination in the nursery must be known. A correlative consideration of importance is the number of years that tree seed remains viable, since old seed must be used when the collection of new seed is impossible.

NUMBER OF SEED PER POUND

Clearly the starting point is the average number of seed per pound, as shown in Table 2. Preferably, number of seed per pound should be determined for each lot. If this can not be done, average values may be used.

TABLE 2.—*Number of seed per pound* [1]

Species	Average	Maximum	Minimum	Tests made
	Number	*Number*	*Number*	*Number*
Western yellow pine	10,000	13,300	6,900	19
Jeffrey pine	4,040	5,400	3,650	12
Sugar pine	2,170	3,200	1,640	38
Douglas fir	35,200	41,230	28,470	18
White fir	16,230	25,000	12,000	17
Incense cedar	15,500	29,000	6,400	55

[1] Northern California seed.

EFFECT OF SOIL ON SEED-TEST VALUES

Parallel tests carried out in the greenhouse on three distinct soil types indicate that the soil itself is important in both rapidity and completeness of germination. The soils employed were river sand; clay, modified by screening and the addition of 10 to 15 per cent by volume of river sand; and a light, lose, porous volcanic soil, roughly classified as lava ash.

The results of tests on three species are summarized in Table 3.

TABLE 3.—*Comparative germination in different soils*

Seed species and kind of soil	Rapidity of germination in—			
	20 days	40 days	60 days	80 days
Western yellow pine:	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Ash	0.5	24.0	60.0	64.0
Sand	.0	16.0	55.0	60.0
Clay	.0	4.0	48.0	54.0
Jeffrey pine:				
Ash	.0	25.5	60.5	66.0
Sand	.5	11.5	62.0	69.5
Clay	.0	7.0	42.0	48.0
Incense cedar:				
Ash	.0	7.0	14.0	15.5
Sand	.0	5.5	22.5	24.0
Clay	.0	2.0	13.0	18.0

For the pines, germination in ash and in sand is similar in rapidity and completeness, exceeding in both the figures for clay soils. For incense cedar the best results are attained in sand, with clay slightly superior to ash. From these tests the presumption is that greenhouse tests made in sand can be applied with a fair degree of safety to nursery sowings in ash soil. If greenhouse tests are applied to sowings in clay soil a material reduction in values appears necessary. These simple tests furnish a partial guide to the application of tests in sand to other soils, but give no answer to the question why and how germination is affected by different soils.

RELATION OF CUTTING, GREENHOUSE, AND NURSERY TESTS

The cutting test is the simplest of all tests and when sowing must be done immediately after seed collection it is the only practicable test.

WESTERN YELLOW PINE

Table 4 summarizes the results of tests made during a 4-year period on western yellow pine seed from northern California. The relations between germination in the experiment station greenhouse and nursery and cutting-test values are remarkably consistent for all lots of seed and for all years. The cutting-test values can be employed for nursery sowings by figuring the germination in the nursery at 75 per cent of cutting-test values.

Table 4.—*Comparative germination percentage in cutting, greenhouse, and nursery tests* [1]

Species	Test			Ratio B to A	Ratio C to A
	Cutting (A)	Greenhouse (B)	Nursery (C)		
Western yellow pine:	*Per cent*	*Per cent*	*Per cent*		
Average	84	67	64	80	76
Maximum	94	83	78	88	83
Minimum	74	58	50	78	68
Jeffrey pine:					
Average	79	66	62	84	78
Maximum	94	82	80	87	85
Minimum	63	45	45	71	71

[1] The maximum and minimum as given are for individual tests showing highest and lowest values. Tests were extended over 120 days.

JEFFREY PINE

Tests of Jeffrey pine seed from northern California made during a 4-year period, also summarized in Table 4, showed relationships that were consistent from year to year and from lot to lot. The values are very close to those for western yellow pine. Cutting-test values for Jeffrey pine are therefore an accurate index of germinability. Nursery germination should average 78 per cent of cutting-test values.

SUGAR PINE

A study of the tests on 40 lots of seed showed no consistency in results from lot to lot or from year to year. Neither was there consistent relation between nursery and green house germination. The result of a single test on any one lot of seed is practically worthless.

INCENSE CEDAR

The behavior of cedar seed is extremely variable and average figures must be used with caution. Parallel tests of a single lot often show wide differences in final germination.

New seed has on the average equal greenhouse and nursery germination, and these values are 40 per cent of cutting test. This figure may be used with some assurance.

DOUGLAS AND WHITE FIRS

Data on these species are too few to permit any general statements.

RAPIDITY OF GERMINATION

Rapidity of germination may be expressed as the percentage of total germination appearing in 10, 20, 30, or more days. Comparisons are also made in some instances by means of what is termed the "rapidity factor," which is the number of days required to produce half of the total germination.

Results of nursery tests for rapidity of germination can only be accepted as a general guide, for they vary greatly in different years, doubtless through the influence of temperature. In one particular they are valid, however. As will be shown later, seeds germinating later than 80 or 90 days after sowing produce small, weak plants unsuitable for transplanting. Therefore, when tests show that on the average no more than a certain percentage of the total germination can be expected in 80 days, allowance for the remaining ineffective seed should be made in calculating the quantity of seed to sow.

WESTERN YELLOW PINE

The results of nursery tests over a 4-year period are summarized in Table 5. On the average, 84 per cent of the germination appeared in 80 days, and this may be accepted as the expected yield of seedlings suitable for transplanting.

JEFFREY PINE

Similar nursery tests for Jeffrey pine are also summarized in Table 5. The values are essentially similar to those for western yellow pine. On the average 79 per cent of the total germination appears within 80 days after sowing and should be effective.

Similar data for other species display such extreme variability as to make averages practically worthless.

TABLE 5.—*Average rapidity of germination in nursery of northern California seed (total period 120 days)*

Species	Rapidity of germination, by 20-day periods, in percentage of total germination[1]—					
	20 days	40 days	60 days	80 days	100 days	120 days
Western yellow pine:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Average	1	14	53	84	97	100
Maximum	4	31	76	93	100	---------
Minimum	0	2	37	66	94	100
Jeffrey pine:						
Average	0	10	46	79	97	100
Maximum	0	42	68	86	98	100
Minimum	0	4	43	75	97	100

[1] Rapidity factors, or the number of days required for 50 per cent germination, are, for western yellow ine, average 59, maximum 44, minimum 71; Jeffrey pine, average 61, maximum 50, minimum 68.

VITALITY OF SEED

Tests of the effect of age on seed of western yellow pine, Jeffrey pine, and incense cedar were made by cutting and also by sowing in both greenhouse and nursery. The results, in the germination of new seed and seed 1, 2, and 3 years old, are shown in Table 6.

TABLE 6.—*Effect of age of seed on germination, as shown by cutting tests and by greenhouse and nursery tests, over a period of 120 days*

Species and age of seed	Test			
	Cutting	Greenhouse	Nursery	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*
Western yellow pine:				
New seed	84	67	64	72
1 year old	86	72	71	76
2 years old	81	75	68	75
3 years old	80	60	56	65
Jeffrey pine:				
New seed	79	66	62	69
1 year old	75	63	61	66
2 years old	77	66	74	72
3 years old	76	62	62	67
Incense cedar:				
New seed	67	27	28	41
1 year old	65	23	20	36
2 years old	67	9	4	27
3 years old	0	0	0	0

WESTERN YELLOW PINE

A very slight falling off in germination is apparent in the western yellow pine seed 3 years old, though the figures for 1 and 2 year old seed are higher than for new seed.

Similar tests on eight lots of western yellow pine seed 4 and 5 years old gave an average of 72.5 per cent compared to an average of 71.7 per cent when the seed was new. It may be accepted that the seed of this species, stored in metal containers in a cool dry place, does not deteriorate for at least five years after collection.

JEFFREY PINE

The data from similar tests on Jeffrey pine seed indicate that Jeffery pine, like western yellow pine, retains its germinating power for at least four years after collection.

INCENSE CEDAR

Cedar, a species with a thin seed coat, behaves very differently from the pines. The initial germination is 40 per cent of cutting test; at 1 year this drops to 35 per cent and at 2 years to 13 per cent. Seed 3 years of age and older did not germinate in this test.

SUMMARY[7]

Western yellow and Jeffery pines display reasonably consistent average values for number of seed per pound, relation of germination to cutting test, and rapidity of germination. For one lot of western yellow pine seed with a cutting test of 84 per cent the following calculation will indicate the average yield of first-class seedlings to be expected:

Number of seeds per pound	10,000
Value by cutting test (84 per cent)	8,400
Probable total germination (75 per cent of cutting test)	6,380
Probable effective germination (84 per cent of total)	5,370

In other words, about 54 per cent of the total number of western yellow pine seed may be counted on to produce seedlings suitable for transplanting. Jeffrey pine has a similar ratio.

The other species exhibit such great variability that average figures for them are less reliable. On the average, sugar pine should give a yield of good seedlings of 25 per cent of seeds sown and incense cedar a yield of 20 per cent.

SOILS AND SOIL TREATMENT

No adequate study has been made of the soils best adapted for raising different species, nor of fertilizing. Nevertheless, certain conclusions are sufficiently proved by experience and by special tests to justify acceptance.

Of the two distinct soil types used in these tests, one a heavy clay loam, the other the light loose "lava ash" of the east slope, the first was in its native condition unsuitable for cultivation because of stickiness when wet and baking and cracking when dry. A liberal addition of sand, changing the physical properties, corrected this condition. No fertilizing has been necessary, though the soil has been used for seven consecutive years. The root systems of all species attained good development in this modified clay soil.

Western yellow and Jeffrey pines, incense cedar, and white fir all grow naturally on the lava-ash soil; sugar pine and Douglas fir but sparingly. Nursery stock of the favorable species developed reasonably satisfactory root systems, and held up well in field tests. Sugar pine and Douglas fir nursery stock, however, was highly unsatisfactory, the rapid drying of the soil and looseness tending to encourage long tap roots and weak lateral systems. After such plants were root pruned for field planting, the root systems were unsatisfactory.

In an effort to make the soil heavier it was limed heavily, and heavy loam was added in the proportions of one-third and one-half.

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[7] Before it was discovered, as will be later explained, that fall sowing would solve the germination problem for such species as sugar pine and white fir, a number of tests were made (3) in an attempt to develop some means of hastening germination, particularly of sugar pine. These included soaking seeds in water, or in solutions of various chemicals, or cracking the seed coats and soaking in water. For sugar pine the only effective method was soaking the seed in a solution of sulphuric acid. Concentrations of 0.5 to 4 per cent and treatment for one hour all gave like results in raising germination from 1 per cent to 6 per cent. Soaking in salt solution raised western yellow pine from 68 per cent to 77 per cent and incense cedar from 26 per cent to 31 per cent. No other species showed as marked results and no other treatment showed conspicuous success for any species. Fall sowing of refractory species appears to solve the problem of prompt germination much more satisfactorily than special treatment of seed, though the latter may be of value where spring sowing must be done.

Transplant stock raised on the altered soils gave the results shown in Table 7. No samples of plants grown on untreated soil were kept, but it is certain that modification of the soil greatly improved root development. Liming appears particularly effective, both in the size of plants obtained and in the very low top-root ratio. Addition of loam is more expensive and less effective.

Soil disinfection with sulphuric acid to prevent damping off has proved desirable at the nursery located in clay soil, and generally unnecessary at the nursery in lava-ash soil.

TABLE 7.—*Effect on sugar pine stock of treatment of lava-ash soil*

Treatment of soil	Weight			Top-root ratio
	Top	Root	Total	
	Grams	*Grams*	*Grams*	
Liming	6.3	5.2	11.5	1.21
Addition of one-third loam	5.5	2.2	7.7	2.50
Addition of one-half loam	4.6	2.4	7.0	1.92

SEASON FOR SOWING

For the sowing of tree seed in large-scale operations the nurseryman in the California pine region has the choice of about a month in either spring or fall during which weather and soil conditions permit satisfactory results. At Pilgrim Creek, in northern California, these months are generally May and November; at Feather River, somewhat to the south and at a lower elevation, the best times are from March 15 to April 15 and from November 15 to December 15. Given these periods for sowing, two questions naturally arise. How early in the spring should sowings be made to bring the best results for the various species? And is spring sowing at the most favorable time as advantageous as fall sowing? The following experiments which serve to answer these questions were carried out at Pilgrim Creek. Experience at Feather River, although not the result of specific tests, amply confirms the conclusions reached at the northern nursery, particularly with regard to the refractory species and to the general advantages of early over late spring sowing.

BEST TIME FOR SPRING SOWING

The first experiments in 1913 were made to test the best time for spring sowing. That year the snow did not leave the ground until May 16, and the first simultaneous tests were made with western yellow pine, Jeffrey pine, sugar pine, Douglas fir, white fir, and incense cedar on that date. A second sowing was made two weeks later, on May 29, and the third on June 15. The same quantity of seed was sown in drills in each instance, and the beds were mulched with burlap and watered twice a day until germination began, and after that once a day. Table 8 gives the period and rapidity of germination for all species with the exception of sugar pine. With this species the tests developed so little as to give no satisfactory figures for comparison.

TABLE 8.—*Rapidity of germination of seed of different species sown at different dates in the spring*

Species and date of sowing	Germination period, in relation to date of sowing		Rapidity of germination on—				
	Started	Ended	June 1	June 15	July 1	July 15	Aug. 1
Western yellow pine:	*Days*	*Days*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
May 16	9	30	20	99	100	----------	----------
May 29	11	75	0	20	60	63	94
June 15	19	61	0	0	0	6	74
Jeffrey pine:							
May 16	12	87	0	30	57	79	97
May 29	16	75	0	2	29	40	55
June 15	20	62	0	0	0	8	55
Douglas fir:							
May 16	18	74	0	22	42	57	100
May 29	23	74	0	0	7	33	83
June 15	20	63	0	0	0	1	85
White fir:							
May 16	21	86	0	2	30	44	68
May 29	28	81	0	0	2	30	60
June 15	32	70	0	0	0	0	44
Incense cedar:							
May 16	22	80	0	10	33	54	83
May 29	29	77	0	0	2	24	55
June 15	31	70	0	0	0	0	52

TABLE 9.—*Comparison of quality of seedlings from spring-sown seed, by species and date of seed sowing* [1]

Species and date of sowing	Length		Average condition of plants
	Top	Root	
Western yellow pine:	*Inches*	*Inches*	
May 16	1.3	11.4	Numerous lateral roots; good 1–0 stock, though somewhat spindly from crowding.
May 29	.8	10.3	Few laterals; healthy; only fair stock.
June 15	.4	9.5	No laterals, healthy but too small for ordinary transplanting.
Jeffrey pine:			
May 16	2.0	14.2	Good stock; numerous lateral roots.
May 29	1.6	12.9	Rather small but fairly good stock; cull 35 per cent for transplanting.
June 15	.6	11.2	Too small and weak for regular transplanting; no laterals on roots.
Douglas fir:			
May 16	1.0	8.8	Good 1–0 stock; damaged by fall frosts; cull 60 per cent for transplanting.
May 29	.6	7.3	Too small to transplant; heavy loss from frosts.
June 15	.5	10.4	Very poor development; entirely too small for transplant stock; 85 per cent loss from fall frosts.
White fir:			
May 16	.3	9.7	Roots fair; too small for good transplant stock.
May 29	.2	10.2	Poorer than first lot.
June 15	.2	10.0	Very poor and weak.
Incense cedar:			
May 16	1.7	11.3	Variable in size, but good stock; good laterals; cull 45 per cent for transplanting.
May 29	.9	10.2	Weak stock; few laterals; not over 25 per cent suitable for transplanting.
June 15	.8	10.2	Poor stock; too small for ordinary transplanting.
1–1 STOCK			
Western yellow pine:			
May 16	3.2	17.0	First-class stock; well-developed root systems.
May 29	2.2	16.5	Too small for desirable 1–1 stock; root systems only fair.
June 15	2.0	12.0	Much too small; root systems very weak.
Jeffrey pine:			
May 16	2.9	18.9	Good stock; suitable for field as 1–1.
May 29	2.7	16.5	Fairly good; can be used for field by culling 25 per cent.
June 15	2.5	15.4	Fair; but too weak for field use.
White fir:			
May 16	2.5	12.6	Good plants but rather small for field use.
May 29	1.6	12.5	Fair plants; too small for practical field use.
June 15	.7	11.9	Entirely too small and weak for practical field use.
Incense cedar:			
May 16	3.2	13.2	Good stock; smaller than from fall-sown seed.
May 29	1.6	13.2	Fair stock; too small for practical field use.
June 15	1.2	12.4	Entirely too small for field use.

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[1] Figures given are the averages of five selected specimens of each lot.

TABLE 10.—*Grading of retransplants (1–1–1 stock) from spring-grown seed, by species and date of seed sowing*

Species and date of sowing	Firsts	Seconds	Culls
	Per cent	*Per cent*	*Per cent*
Western yellow pine:			
May 16	90	8	2
May 29	86	12	2
June 15	84	14	2
Jeffrey pine:			
May 16	91	8	1
May 29	85	12	3
June 15	83	15	2

Tables 9 and 10 permit a further comparison of the plants of most of the species as they developed during the three years that the study was continued. Table 9 shows the development at the end of one year in the seed bed, and also measurements taken a year later, when the seedlings had experienced a year of growth in the transplant bed. Table 10 indicates the results of a second transplanting of the best specimens and the relative progress of these retransplants at the end of the year. These data deserve detailed consideration by species.

WESTERN YELLOW PINE

The western yellow pine seedlings came up in two distinct germination periods (fig. 2), the first from June 1 to July 1, including

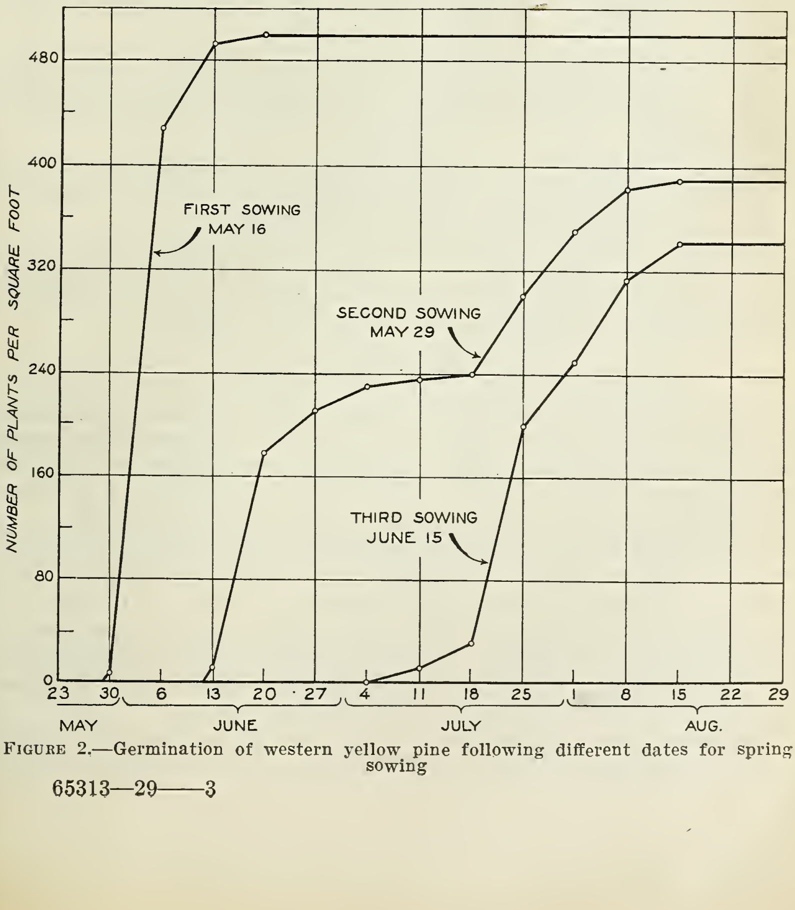

FIGURE 2.—Germination of western yellow pine following different dates for spring sowing

practically all of the earliest sowing, and the second from July 18 to August 18. The low germination during the interval in early July was due to unseasonably cold weather. It may be supposed that germination from the second sowing would have continued the rapid progress indicated on July 1, when nearly 60 per cent of the germination had taken place, had it not been for the change in the weather. It is possible also that germination from the third sowing would have been well under way somewhat earlier. It is noteworthy that the break in growth curves produced by the cold spell is more marked for the western yellow pine than for any other species.

In addition to the greater rapidity of germination from the earliest sowing, it is recorded that this sowing produced 28 per cent more seedlings per unit area than did the second and 47 per cent more than did the third sowing. A graphic illustration of the course of germination for each of the three sowings is given in Figure 2.

A comparison of the quality of stock at the end of the first year (Table 9) indicates that the earliest sowing produced the best stock and that the plants from the last sowing, though in good condition, were on the average too small to transplant. Although only 8 inches of the roots would be saved in transplanting, the length of the root as given in the table is a very accurate indicator of the quality of stock. Comparing these results with Figure 2, it is possible to draw the conclusion that western yellow pine seed which germinates after July 15 produces plants that are too small for transplanting as 1-year seedlings.

Comparison of the transplants at the end of the second year (Table 9) confirms the indications of the earlier observations. The stock from the earliest sowing retains its superiority and is indeed the only really good lot.

The grading of the stock retransplanted and lifted at the end of the third year (Table 10) maintains the superiority of the early sowing. Typical specimens are shown in Figure 3.

The results with western yellow pine stock indicate very clearly that the early spring sowing results in the most rapid and complete germination with the largest number of plants, and also in the best-developed plants, whether as 1–0, 1–1, or 1–1–1 stock.

JEFFREY PINE

The germination of Jeffrey pine seed (Table 8) was considerably lower than that of western yellow pine, but the indication with regard to time of sowing was the same—namely, that early sowing (May 16) gives notably the best results. Practically 80 per cent of the total germination from the early sowing was completed by July 15.

In quality of stock the results of Jeffrey pine shown in Tables 9 and 10 very closely resemble the figure for western yellow pine. The indication is that the earliest sowing produces much the best quality of plants and that the last sowing yields plants that at no time are suitable for use in the field. The final date for effective germination is perhaps a little later than for western yellow pine, being some time between July 15 and August 1, probably about July 20.

Transplants from the second sowing were in a little better shape for field work than were the western yellow pine transplants, but the retransplants at the end of the third year are, if anything, less satisfactory.

The general conclusions are the same as those for western yellow pine. Spring-sown seed should be placed in the ground at the earliest possible moment, and these seeds will germinate more quickly and completely than seed sown later and produce a greater number of superior plants both for transplanting and for field work.

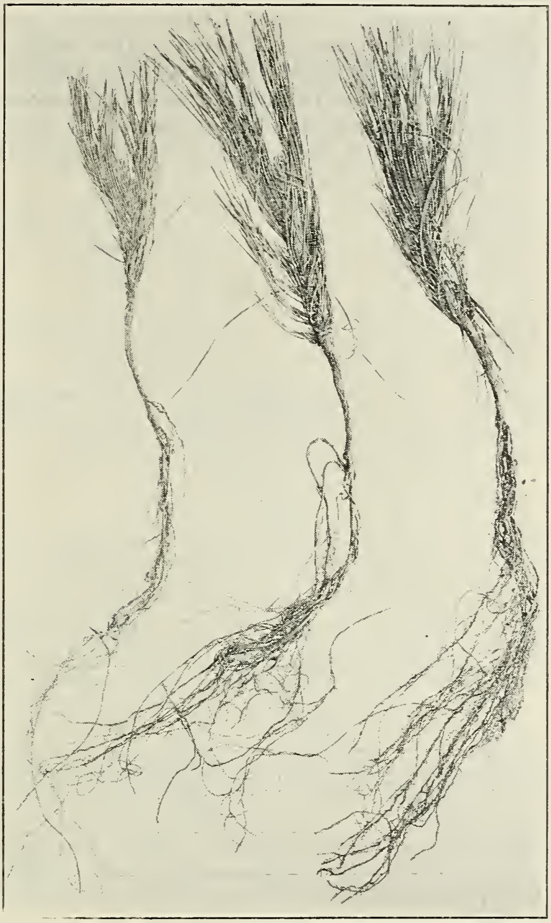

FIGURE 3.—Typical early-sown western yellow pine retransplants (1–1–1 stock). Ground lines form 1-inch squares

SUGAR PINE

Spring sowing of sugar pine in these tests gave such slight results in germination as to deserve little consideration although these apparently confirmed the results obtained from the other species.

DOUGLAS FIR

The germination of Douglas fir as shown in Figure 4 and Table 8 was slow in all lots, although there is little doubt that the first sowing is the most satisfactory. This sowing also produced 24 per cent more plants than the second and more than twice as many as the third.

The quality of stock at the end of the first year was very much affected by fall frosts, so much so that even the stock from the first sowing, the only one suitable for transplanting, had to be culled 60 per cent. It is apparent that Douglas fir seed germinating after July 1 produces plants too small for transplanting as 1–0 stock. This species must obviously have full opportunity for growth during the summer if it is to withstand the severe cold that is likely to be experienced in the fall.

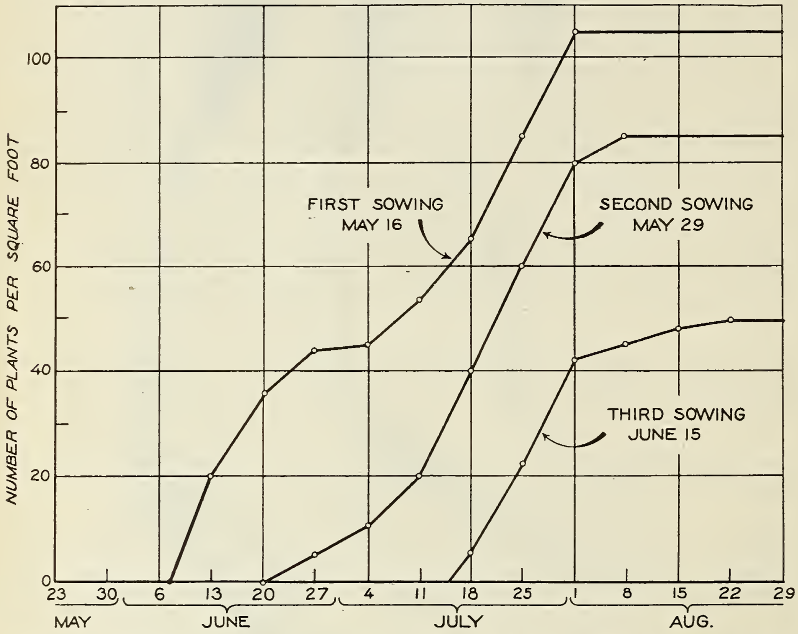

FIGURE 4.—Germination of Douglas fir following different dates for spring sowing

While it was impossible to carry the tests of quality of stock beyond the first year, the evidence is ample that, with this species as with those noted above, the earliest possible spring sowing is the most advantageous.

WHITE FIR

The germination curves for spring-sown white fir were very similar in form to those for Douglas fir. Although germination was very slow for all sowings (Table 8), the relation between the lots was about the same as with the other species. The germination from the first sowing, in addition to being much more rapid than the other, resulted in 4 per cent more seedlings than the second sowing and 32 per cent more than the third.

Quality of stock was not very encouraging. All the seedlings were very small. (Table 9.) This is a characteristic of the species, and experience has shown that white fir seedlings should be left in the seed beds for two years before transplanting. Tests made, however, on 1–1 stock indicated (Table 9) that early sowing would produce much better plants than later sowings, even though the plants were too small for field use.

The best of the 1–1 stock was retransplanted, and as 1–1–1 stock the first sowing produced 40 per cent firsts. The firsts from the other sowings were negligible—8 and 2 per cent, respectively. The indication is that the characteristics of seedlings are maintained in spite of two transplantings. The conclusion to be drawn from the white fir tests as a whole is undoubtedly that early spring is more advantageous than late spring sowing.

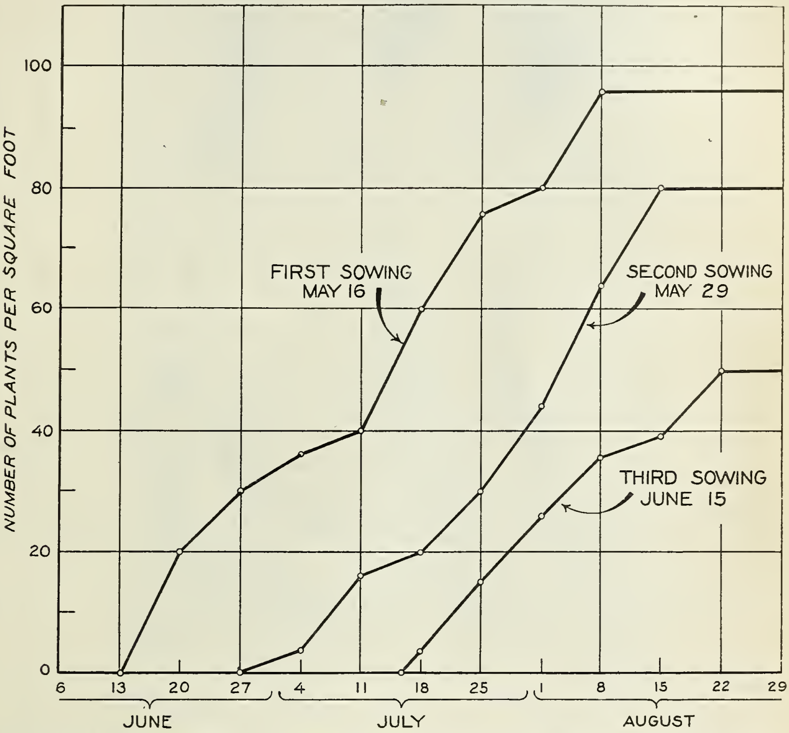

FIGURE 5.—Germination of incense cedar following different dates for spring sowing

INCENSE CEDAR

The germination curves for all three sowings of incense cedar as shown in Figure 5 have the same general form as those for the other species. In total number of plants produced the early sowing gave 22 per cent over that of the second sowing and 96 per cent more than the third. The rapidity of germination is greater than that of white fir (Table 8), and the quality of stock (Table 9) is somewhat better. The indication is that only seeds germinating before July 15 produce stock suitable for transplanting. The superiority of stock from the early sowing is quite evident through the first two years. The results in firsts for the three lots as recorded at the end of the third year from 1–1–1 stock were respectively 81, 86, and 81 per cent. The development of the plants at this stage is well shown in Figure 6.

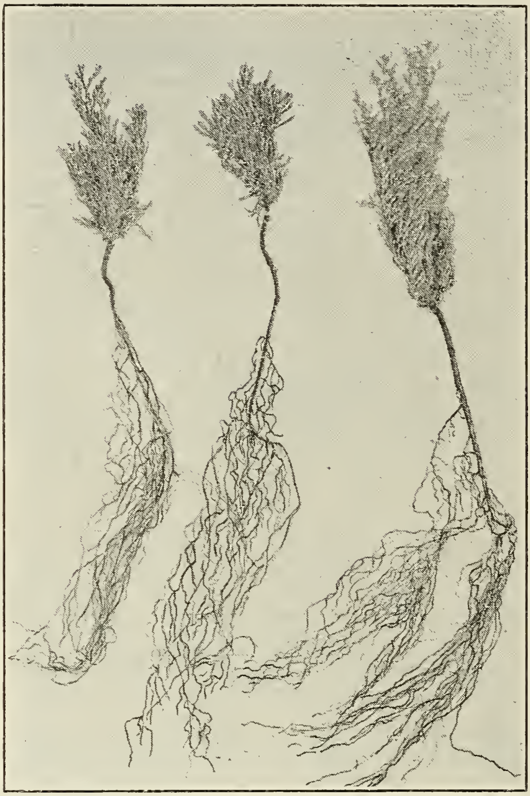

FIGURE 6.—Typical early-sown incense cedar transplants (1–1 stock). Ground lines form 1-inch squares

As with the other species, early spring sowing of incense cedar is indicated clearly as the most advantageous in greater production of seedlings and better development of plants.

SPRING SOWING VERSUS FALL SOWING

The conclusion very definitely indicated in the preceding section, that when seed is spring sown the sowing should be done at the earliest opportunity, leads naturally to a consideration of whether or not spring is the better season in which to sow the seed. Tests of spring versus fall sowing were made at Pilgrim Creek November 26, 1914, and April 28, 1915, for most of the species, supplementing preliminary tests of the preceding year. The results are indicated below under the several species.

WESTERN YELLOW PINE

The western yellow pine tests were conducted in 1914 and 1915 only. The germination data are shown in Figure 7 and also in Table 11. The total germination was the same from both sowings, but the fall-sown seed completed germination 42 days earlier than the spring-sown. Nevertheless, 80 per cent of the spring-sown seed had germinated by June 18 which is about one month before the final date for effective germination, and by that date 100 per cent had germinated.

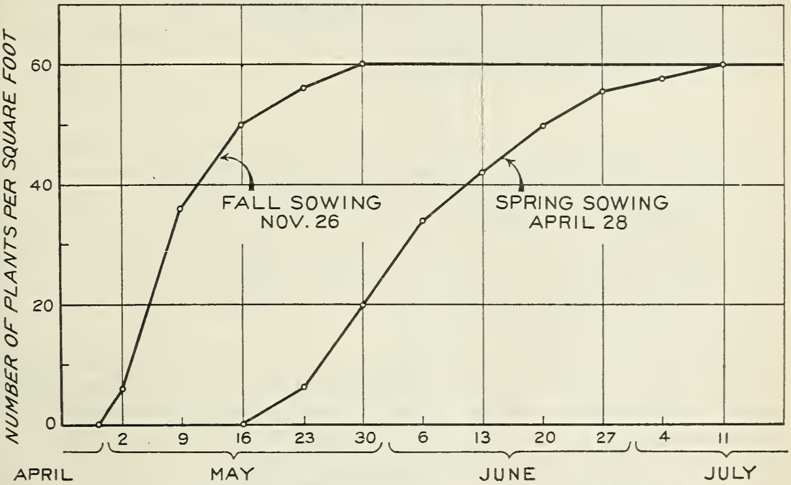

FIGURE 7.—Germination of western yellow pine from fall and spring sowings

TABLE 11.—*Comparison of quality of western yellow pine and Jeffrey pine 1–0 seedlings from fall and spring sowing* [1]

Species and date sown	Firsts	Weight		Top-root ratio
		Top	Roots	
Western yellow pine:	*Per cent*	*Gram*	*Gram*	
November 26	70	0.29	0.10	2.9
April 28	67	.26	.15	1.7
Jeffrey pine:				
November 11	67	.44	.17	2.6
May 4	81	.31	.13	2.4

[1] Each value is the average of 25 plants.

Although the results in effective germination are equally satisfactory for spring or fall sown seed, a very distinct difference is apparent in quality of stock produced, as is shown in Table 11. This comparison made at the end of the first year by averaging 25 normal plants from each sowing, reveals in comparative development a profound difference that is not apparent in the percentage of firsts from the two sowings. Although the total weight is practically the same in both instances, the ratio between top and root varies widely and indicates clearly the superiority of the stock from spring-sown seed. Plantings at Feather River have shown clearly that the top of a 1–0 western yellow pine seedling is overdeveloped when the ratio exceeds 2.

Other tests of fall and spring sowing brought out an additional disadvantage in the fall sowing of western yellow pine. Very heavy frosts are not uncommon in early May, reaching a temperature of 23° to 24° F., and in two different years the early seedlings from fall sowing have been severely damaged, 50 to 80 per cent being killed outright and many of the rest being deformed.

The evidence is that for western yellow pine early spring sowing gives the most satisfactory results.

JEFFREY PINE

Comparative sowings of Jeffrey pine seed were made in the fall of 1913 and spring of 1914 and also in the fall of 1914 and spring of 1915. The germination data are strikingly similar to those for western yellow pine. Although spring sowing resulted in a slightly larger number of seedlings because of loss from frosts, fall sowing resulted in germination completed 27 days before that from spring sowing. Here also practically all of the spring germination (94 per cent) appeared before July 15.

In quality of stock the percentage of firsts obtained was on the average 75 per cent from fall sowing and 85 per cent from spring sowing. This added to the slightly greater total germination for spring sowing indicates, though not decisively, the superiority of spring-sown plants. In comparative development, as indicated in Table 11, which shows the average of 25 plants of each lot, fall sowing makes a somewhat better showing than spring sowing in number of firsts and total weight of fall-sown seedlings; but the ratios are practically equal.

The evidence is not so clear as it was for western yellow pine. Fall-sown seed results in plants that make greater development but are subject to loss from early frosts. Seedlings from spring-sown seed include a greater number of firsts and suffer less loss from frost. Spring sowings are practically equal with the fall sowings in effective germination. On the whole early spring sowing is indicated as preferable.

SUGAR PINE

Table 12 gives the data resulting from two comparative tests of fall and spring sowing made at the same time as those for Jeffrey pine. In the first tests the total germination from spring sowing was only 20 per cent of that from fall sowing, and in the second test only 15 per cent. In both tests the germination from spring-sown seed dragged on till the end of August.

Table 13 shows the condition of this same stock from fall and spring sowings after one year in the transplant bed. The evidence here seems to be overwhelmingly in favor of fall-sown seed, and this conclusion is amply supported by the results of general planting practice in this region. Sugar pine is a difficult species to germinate, and although spring sowing occasionally results in a satisfactory stand of seedlings, it more often produces plants that are very small and of uneven development. Fall sowing for sugar pine is by all means the more desirable.

TABLE 12.—*Comparison of quality of sugar pine seedlings from fall and spring sowings*

Date sown	Total germination before June 15	Length		Average condition of plants
		Top	Roots	
	Per cent	*Inches*	*Inches*	
Nov. 27, 1913	100	3. 0	14. 1	First-class stock; well developed and uniform.
May 30, 1914	0	1. 2	12. 3	Only fair; cull 50 per cent for transplanting.
Nov. 6, 1914	100	3. 1	15. 2	Practically identical with other fall-sown stock.
Apr. 28, 1915	33	1. 5	13. 1	Mediocre stock; small for transplanting.
Average of fall sowings	100	3. 0	14. 6	
Average of spring sowings	16	1. 4	12. 7	

TABLE 13.—*Grading of 1½–1 (fall-sown) and 1–1 (spring-sown) sugar pine and incense cedar transplants*

Species and seed class	Firsts	Seconds and culls	Dead
	Per cent	*Per cent*	*Per cent*
Sugar pine:			
Fall-sown (1½–1)	37	60	3
Spring-sown (1–1)	0	47	53
Incense cedar:			
Fall-sown (1½–1)	87	11	2
Spring-sown (1–1)	57	31	12

DOUGLAS FIR

No purely experimental fall sowing was made for Douglas fir, but general tests indicate that it is almost impossible to protect seedlings from frost when they are produced so early in the spring. In every instance where fall sowing was tried the entire crop was wiped out the following spring. For this reason spring sowing of Douglas fir is imperative.

WHITE FIR

The seedlings from fall sowings of white fir were also badly hit by spring frosts. Three separate tests gave the same results. However, seedlings from fall sowing that survived were distinctly superior to those from spring sowing.

In eight years of practice with white fir the species has come to be classed as refractory: not so much so as sugar pine but more refractory than incense cedar. When the seed is spring sown the germination progresses very slowly, dragging out to August, with consequent damage from fall frosts. The losses from spring frosts when seeds are sown the preceding fall can be overcome by properly screening the beds at night. Where this protection is given, the prompt and uniform germination indicates that fall sowing is the best practice for white fir.

INCENSE CEDAR

The results of comparative fall and spring sowings of incense cedar are shown in Figure 8. In these tests fall sowing produced 25 per cent more plants and resulted in germination complete more than a month before that from spring sowing. Although this germination was more rapid than normal, the indications are that a distinct lead would be maintained in any year. At the end of the year it was found that the plants from fall sowing were twice as high as the others, had better root development, and were more uniform in size. When, after one year in the transplant beds, the stock was again examined, the comparative grading, as given in Table 13, again indicated clearly the superiority of fall sowing. This is also obvious from the examination of the plants afforded in Figure 9.

Fall sowing for incense cedar produces more plants suitable for transplanting than those of spring sowing and more and better transplants. The only drawback is the susceptibility to late spring frosts, but this can be minimized by proper care.

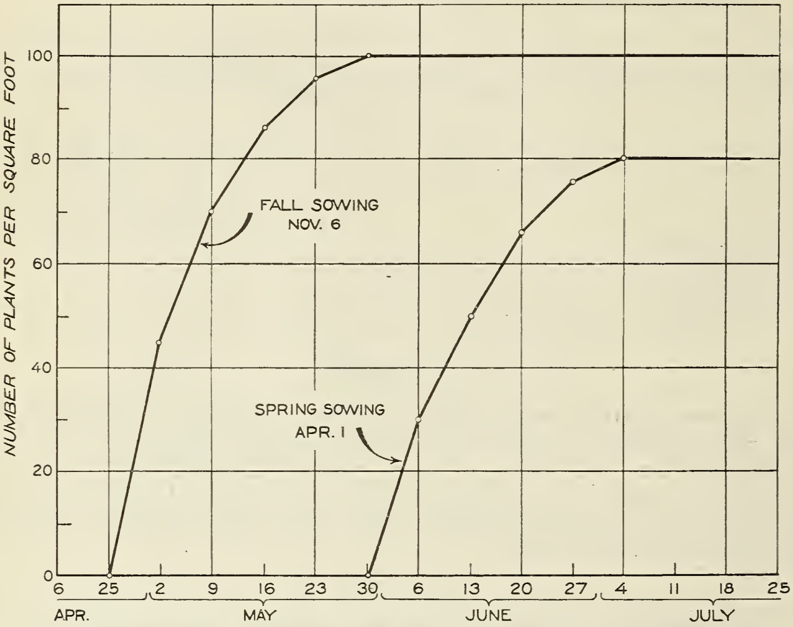

FIGURE 8.—Germination of incense cedar from fall and spring sowings

SUMMARY

Fall sowing gives earlier and more rapid germination of all species than does early spring sowing. This results in larger and heavier plants, but it also exposes the young seedlings to damage from spring frosts. Western yellow pine and Jeffrey pine, which germinate rapidly, produce better plants from spring-sown seed than from fall-sown. The more refractory species—sugar pine, white fir, and incense cedar—can only attain a satisfactory development when fall sown. They must, however, be protected in their first year from the spring frosts. Douglas fir seedlings produced from fall-sown seed are so highly susceptible to damage from spring frosts as to make spring sowing the only practicable method for this species.

DENSITY OF SOWING

The seed-test values already discussed indicate the quantity of seed that must be sown to obtain any specified yield of seedlings, but a question which the nurseryman must consider is the density of his sowing, or the number of seedlings that may profitably be grown in a unit of area.

The experiments to determine the answer to this question for western yellow pine, Jeffrey pine, sugar pine, Douglas fir, white fir, and incense cedar were carried out at Feather River and were designed to determine the proper density for seedlings to be employed as 1–0 stock and for those to be used as 2–0 stock. The results are given below under the various species. Sowing in drills 1 inch wide and 6 inches apart was employed in each instance, and the results were recorded for density of stock per linear foot of drill.

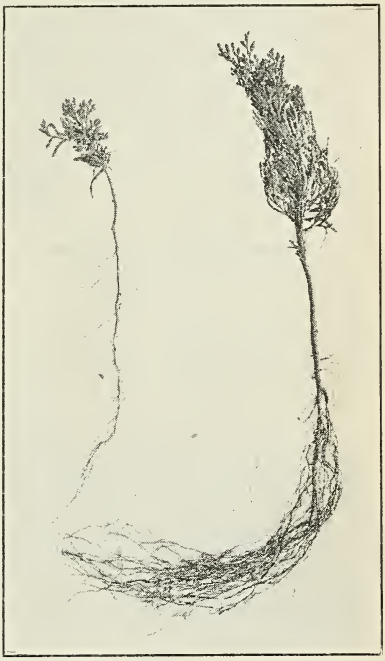

FIGURE 9.—Spring-sown (left) and fall-sown (right) incense cedar transplants (1–1 stock). Ground lines form 1-inch squares

WESTERN YELLOW PINE

The tests for western yellow pine were made from spring sowings only. Table 14 gives an idea of the results for 1–0 stock. With increasing density the total number of seedlings increases, but the percentage of firsts decreases. Weight, which is perhaps the best single index of development, increases up to a density of 90 and thereafter decreases rapidly. Plants from densities of 100 or more had weak tops. The excellent proportions of plants from densities of 70 to 100 more than balances the advantages of other densities in number or percentage of firsts, and indicates that a density of 70 to 100 plants per linear foot of drill is best for western yellow pine seedlings when they are to be transplanted as 1–0 stock.

The results when 2–0 stock is grown are markedly different from those of 1–0 stock, as is shown in Table 15. Here increase of density gives a steady decrease in weight and in percentage of firsts. Tests of field survival made in 1917, using 100 plants in each lot, point directly to a density of 30 as the most suitable, and this is corroborated by the very satisfactory ratio of top to root for this density. In both these particulars lighter and heavier densities are less favorable. The evidence is clear that for 2–0 stock a density of 30 plants to the linear foot is the most satisfactory.

TABLE 14.—*Effect of density of sowing on production and size of 1–0 western yellow pine seedlings* [1]

Seedlings per foot of drill (number)	Graded as firsts		Average size, top plus root	
			Length	Weight
	Number	*Per cent*	*Inches*	*Gram*
30	23.2	77.3	12.0	0.18
40	27.0	67.5	11.7	.20
50	29.5	59.0	11.5	.22
60	31.5	52.5	11.2	.24
70	32.9	47.0	11.0	.25
80	35.2	44.0	10.8	.26
90	37.8	42.0	10.6	.31
100	40.0	40.0	10.4	.26
110	42.9	39.0	10.2	.24
120	45.6	38.0	10.0	.22
130	48.1	37.0	9.7	.20

[1] Data curved.

TABLE 15.—*Effect of density of sowing on production and size of 2–0 western yellow pine seedlings*

Seedlings per foot of drill (number)	Firsts	Weight, root and top	Top-root ratio	Field survival
	Per cent	*Grams*		*Per cent*
10	84.6	3.976	2.23	13
20	68.4	2.827	1.86	12
30	55.8	2.533	1.50	35
40	40.0	2.418	2.02	11
80	25.8	1.098	2.59	3

JEFFREY PINE

Experiments in density of sowing for Jeffrey pine resulted in data so closely resembling those for western yellow pine that it is only necessary to summarize the conclusions to be drawn from them. Densities of 60 to 80 gave the best results both in production and in quality of plants where 1–0 stock was desired. This superiority was maintained in the transplant beds, in percentage of firsts, in quality of stock, and in field survival. The variations in the other densities were similar to those for western yellow pine. For 2–0 stock a density of 30 to 35 plants per foot of drill proved to be the best of the densities, which ranged from 10 to 80. The weight ratio was most favorable at this point. Survival in the field was 38 per cent for density 30, compared to 27 per cent for density 20, and 25 per cent for density 40.

SUGAR PINE

The experiments with fall-sown sugar pine seed were so seriously disturbed by losses that no clear-cut results were obtained. The indications were that this species does best at the same density as Jeffrey pine—60 to 80 plants per linear foot of drill for 1–0 stock. This density has given satisfactory results in general practice and may be accepted as correct.

In determining the best density for 2–0 stock three densities were tried, of which the lightest sowing—40 plants per linear foot of drill—gave the most complete germination and a loss of 10 per cent, which was low compared to losses of 21 and 29 per cent for the medium and heavy sowings. The number of firsts was slightly greater from the light sowing than from the others, and the total weight and top-root ratios were at least as satisfactory. The optimum density of 30 to 35 seedlings per linear foot for 2–0 stock of Jeffrey and yellow pine holds also for sugar pine.

DOUGLAS FIR

The test with Douglas fir were applied to 2–0 stock only, since 1–0 seedlings are generally too small to transplant. Three densities were used, of which the medium density avoided, on the one hand, weakness in the top and, on the other, overdeveloped tops. As is indicated in Table 16, the production of firsts did not differ greatly, but a more marked difference is noted in the development of the plants. The stock from heavy sowing is decidedly superior in weight and top-root ratio. Although these figures would favor light density as the best, other considerations, including general condition of the plants and survival in the field, indicate that sowing to medium density of 30 to 40 plants per linear foot of drill is the best practice for raising 2–0 Douglas fir stock.

Table 16.—*Effect of density of sowing on production and size of 2–0 Douglas fir seedlings*

Seedlings per foot of drill (number)	Total weight	Top-root ratio	Firsts per foot
	Grams		*Number*
20	30. 1	1. 95	13. 0
40	35. 5	1. 44	9. 6
60	41. 9	1. 11	10. 0

WHITE FIR

As with Douglas fir, only 2-year-old white fir seedlings need to be considered since 1–0 seedlings are too small to handle in transplanting. Sowings were made to produce 20, 40, and 60 plants per linear foot of drill. Practically the same number of firsts were produced for all three sowings; also no pronounced difference in weight or in balance could be detected. The only distinguishing feature of any importance was a slightly larger yield of firsts from the heavy sowing, and for this reason a density of 50 to 60 plants per linear foot of drill is indicated as the best for white fir.

INCENSE CEDAR

Three sowings, to produce 20, 40, and 60 plants per linear foot, were made for incense cedar as for Douglas fir and white fir; but tests were made with both 1–0 and 2–0 stock. Examination of the 1–0 stock showed 30 firsts per foot for medium and heavy sowings and only 18.6 for the light sowing. Seedlings from the light sowing were also inferior in balance, having overdeveloped tops. Densities of 60 to 80 plants per foot of drill are indicated as the best for 1–0 stock of incense cedar. The experiments with 2–0 stock indicated the best densities to be from 35 to 40.

SUMMARY

Number of plants per unit of area appears to depend primarily on the size of the individual plants. For 1–0 stock, the relatively large sugar pine, Jeffrey pine, and incense cedar do better when fewer seedlings are grown, and the small Douglas fir and white fir give better results with a greater density. Western yellow pine is intermediate. Sowing too heavily with any of the species produces spindling plants with poor root systems, while sowings that are too light in density tend to an overdevelopment of the top. A satisfactory top-root ratio is usually obtained with plants from sowings of medium density. The best density for 1–0 stock for all species is about two to two and one-half times as great as the best density for 2–0 stock.

DEPTH TO SOW

Experiments in depth of sowing (*2*) were carried out at Feather River with spring-sown seed of the six species used in the other tests. In addition, tests were made with fall-sown sugar pine and incense cedar. The seed was sown in drills under sand, the drills being covered with burlap until germination started. All control conditions were standardized.

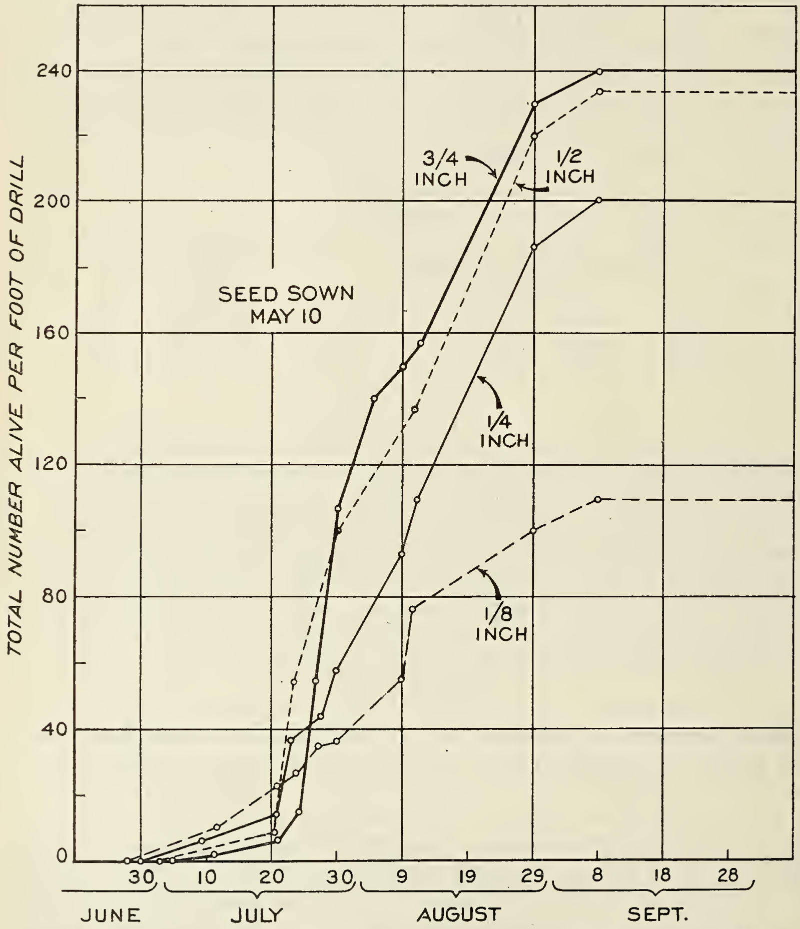

FIGURE 10.—Influence of depth of sowing on the germination of western yellow pine

WESTERN YELLOW PINE

The march of germination of western yellow pine seed at the different depths is shown in Figure 10 and in Table 17. It is evident that germination starts first in the shallow drills but when once started is more rapid and complete in the deeper drills. Delayed germination occurred in the ¼ and ½ inch sowings.

TABLE 17.—*Rapidity of germination of seed of western yellow pine and Jeffrey pine sown at different depths*

Species of seed and depth of sowing	Rapidity of germination in—				
	20 days	30 days	40 days	50 days	60 days
Western yellow pine:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
⅛-inch	2	9	19	33	63
¼-inch	0	3	4	28	48
½-inch	0	1	2	43	55
¾-inch	0	0	1	44	62
Jeffrey pine:					
¼-inch	3	13	24	45	88
½-inch	1	6	8	53	89
¾-inch	0	5	9	62	96
1-inch	0	3	8	63	100

The final test of the different depths of sowing must be in terms of quantity and quality of stock produced, and quality must be judged mainly by the number of first-class seedlings. These data are given in Table 18 for the seedlings at the end of the first year. It will be seen that there is a wide range in the total number of seedlings at different depths, but very little variation in the number of first-class seedlings. The ½-inch and ¾-inch sowings produced the largest number of firsts, and, of these ½-inch had the higher percentage of firsts. Therefore, the ½-inch sowing may be said to be the best of the four depths. The firsts from all depths were of the same average size and quality. For this species shallower sowings (one-eighth and one-fourth of an inch) are, on the basis of firsts, only 80 per cent as effective as either of the deeper sowings.

TABLE 18.—*Quantity and grading of seedlings (1–0 stock) of different species from seed sown at various depths*

Species	Season of sowing	Depth of sowing	Total per foot	First-class seedlings per foot	
		Inch	*Number*	*Number*	*Per cent*
Western yellow pine	Spring	⅛	30	22	73
		¼	40	23	58
		½	48	28	58
		¾	58	28	48
Jeffrey pine	do	¼	44	31	70
		½	62	39	63
		¾	51	30	59
		1	37	26	70
Sugar pine	do	¼	42	26	62
		½	45	21	47
		¾	25	13	52
		1	22	13	59
Do	Fall	¼	48	25	52
		½	48	28	58
		¾	45	26	58
		1	35	20	57
Douglas fir	Spring	⅛	47	20	43
		¼	40	17	42
		½	30	16	53
		¾	17	10	59
White fir	do	⅛	43	27	63
		¼	31	17	55
		½	13	7	54
		¾	4	2	50
Incense cedar	Fall	¼	42	24	57
		½	48	34	71
		¾	22	15	68
		1	22	16	73
Incense cedar (2–0 stock)	Spring	¼	22	10	45
		½	10	5	50
		¾	10	5	50
		1	3	2	67

JEFFREY PINE

The four sowings for Jeffrey pine were from one-fourth of an inch to 1 inch in depth instead of one-eighth to three-fourths inch, as with western yellow pine. The rate of germination at the different depths is indicated in Table 17, and the quality of stock produced in Table 18. Jeffrey pine starts much more quickly in the deeper drills than does western yellow pine. The shallow seed had only five days' advantage over the deeper seed, and for all lots the peak of germination was practically the same. As a group, the shallowest sowing (one-fourth inch) and the deepest sowing (1 inch) attained less than 75 per cent of the total germination of the group comprising the two intermediate sowings, and only 83 per cent of the number of first-class seedlings. The average size and development of firsts was the same in all lots. Of the four sowings, that at one-half inch produced the greatest number of firsts, and is therefore indicated as the best for spring sowing.

SUGAR PINE

The spring sowings for sugar pine were rather unsatisfactory owing to the heavy hold-over germination. Briefly summarized, they indicate that in the production of first-year seedlings from spring-sown seed the shallower sowings are five times as effective as the deeper sowings. However, loss in winter is much more severe among the shallow-sown seedlings. Hold-over germination is practically the same for the shallower sowings and the deeper sowings, but the rate of loss during the second summer is greater for the deeper sowings. The net result is twice as many 2–0 seedlings from the shallow as from the deeper sowings.

TABLE 19.—*Comparative development of plants of different species from seed sown at various depths*

Species	Season of sowing	Depth of sowing	Weight			Top-root ratio
			Top	Root	Total	
		Inches	*Grams*	*Grams*	*Grams*	
Sugar pine	Spring	¼	1.70	0.58	2.28	3.0
		½	1.50	.50	2.00	3.0
		¾	1.43	.44	1.87	3.2
		1	1.21	.40	1.61	3.0
	Fall	¼	1.03	.39	1.42	2.5
		½	1.03	.40	1.43	2.5
		¾	1.24	.55	1.79	2.3
		1	1.16	.52	1.68	2.2
White fir	Spring	⅛	4.26	1.62	5.88	2.6
		¼	3.90	1.20	5.10	3.2
		½	3.85	1.07	4.92	3.6
		¾	3.82	.95	4.77	4.0
dar (1½–0 stock)	Fall	¼	15.47	5.02	20.49	3.1
		½	26.00	12.80	38.80	2.0
		¾	29.95	11.95	41.90	2.5
		1	44.80	17.10	61.90	2.6

The tests of fall-sown seed showed a definite division into the same two groups of shallower and deeper sowings so far as the activity of germination was concerned, but in survival after the first year those sown at a 1-inch depth stood out as much less satisfactory. The two shallower sowings started germination and reached their peak two weeks earlier than the deeper sowings, but in the final count the 1-inch sowing attained only 140 plants per 4-foot drill in comparison with an average of 188 plants for the other three depths.

Number and quality of stock are indicated in Tables 18 and 19. The general conclusion is that shallower sowings (one-fourth and one-half of an inch) are best because of higher germination the first year and the greater number of all plants and of first-class seedlings produced per unit area. The plants from these sowings are also larger and equally well developed.

Although it has already been shown that spring sowing is not practicable for sugar pine, it is interesting to note that of the three shallower depths giving practically the same number of first-class seedlings per foot of drill the ¾-inch sowing gives the best results in sturdiness or development and also in weight ratio. It is evident that three-fourths of an inch or possibly one-half of an inch would be preferable for fall sowing.

DOUGLAS FIR

Tests of Douglas carried out in 1913 and 1914 indicated that germination starts soonest and is most rapid and complete from shallowest sowing, which for this species, as for western yellow pine, was one-eighth of an inch. Table 18 shows the average yields for the two tests, the respective values being practically the same. The total number of plants and of first-class seedlings per foot of drill vary inversely with the depth of sowing. The values for one-eighth and one-fourth of an inch are above the average for all depths. The percentages of firsts vary directly with the depth of soil.

The average weights were nearly identical for all depths, but the tops of the plants from shallow sowing were slightly longer than those from the deeper sowings because of the longer period of growth. After a year as transplants the ⅛ and ¼ inch sowings maintained a slightly higher number of first-class plants than the other depths, and as these two lots produced also a greater total number of seedlings and somewhat larger plants they indicate the shallower depths as preferable for these species.

WHITE FIR

Rapidity of germination of white fir followed closely the trend of Douglas fir, the shallowest sowing produced the earliest seedlings and the most rapid and complete germination. Tables 18 and 19 show that the ⅛-inch sowing produces the greatest number and percentage of first-class seedlings, and that these seedlings have the the best top-root ratio of the four lots.

INCENSE CEDAR

The march of germination for this species was so similar to the others that the conclusions may be briefly summarized. For fall sowings the total germination for the ¼ and ½ inch depths together was 80 per cent higher than the total for ¾ and 1 inch depths. Tables 18 and 19 give the average results from fall sowing in quantity and development of seedlings. The ½-inch sowing gives the largest number of seedlings per foot of drill, and also the greatest number of first-class seedlings. Although these seedlings are not the largest or heaviest, they attain the most favorable top-root ratio and in view of their superiority otherwise establish clearly the ½-inch sowing as the best for incense cedar at this time of year.

It is interesting to compare the results also given in Table 18 of the several lots of spring-sown seed after two years in the seed bed, when the hold-over germination could be figured in. Evidently the ¼-inch sowing has produced the largest total number of seedlings and the greatest number of first-class plants. Examination for quality of stock also supported this lot as superior to the others.

SUMMARY

For all the species it may be said that germination will start earlier from the shallower drills, and that this germination will be overtaken and surpassed later on by the deeper drills.

For the pines, total germination is generally greatest in the ½-inch drills, sugar pine favoring if anything a shallower sowing. It is probable that the deeper coverings prevent germination of the weaker seed by the greater weight of the sand cover. Total germination of the firs and incense cedar generally varies inversely with the depth, probably from the same cause.

There is a marked tendency for the percentage of the first-class seedlings to vary directly with the depth, probably because the deeper sowings tend to eliminate the germination of the weaker seeds, and hence the production of weak plants.

Except for white fir and incense cedar, the top-root ratio seems fairly constant for all depths.

In general, the heavy-seeded species—sugar pine (averaging 2,000 to the pound), Jeffrey pine (averaging 4,000 to the pound), and western yellow pine (averaging 10,000 to the pound)—require deeper sowing than the light-seeded Douglas fir (35,000 to the pound), white fir (16,000 to the pound), and incense cedar (15,500 to the pound.)

DRILL VERSUS BROADCAST SOWING

Experiments designed to determine the relative advantages of drill and broadcast sowing were carried out in 1917. Three specific points on which information was sought were: The relative production of "firsts" per bed when sown to the same total amount of seed; the relative cost of sowing, weeding, cultivating, etc.; and the relative loss by the two methods.

The sowings were planned to produce 100 plants per linear foot of drill and 200 plants per square foot of seed bed. Drills were laid out 6 inches apart. The experiments were made only with western yellow pine, previous work having shown that results with that species could be safely applied to Jeffrey pine at least.

A close observation of the course of germination disclosed no material difference between the two methods of sowing. The drill sowing produced 50 per cent of total germination two days later than the broadcast, but the curves for both were practically identical throughout. In total germination on the sample areas studied in detail the figures were: Per linear foot of drill 94.5 plants; per one-half square foot of seed-bed (corresponding area) 99 plants.

At the end of the season a complete inventory of one-half of a 4 by 12 foot seed bed for each method of sowing showed the results given in Table 20. In total production and in number and percentage of firsts (plants suitable for transplanting) no material differences appeared. Damping-off was a factor of loss in the drill sowing but was of very minor importance in the broadcasted bed. However, hand weeding of the latter bed was necessary, and this resulted in some loss, chiefly of the smaller and weaker seedlings. In so far as production is concerned, no differences in favor of either method were found.

Table 20.—*Quantity and grading of 1–0 western yellow pine from seed sown, drill and broadcast*

Method of sowing	Plants per unit area	First-class seedlings per foot		Loss per foot	Principal cause of loss
	Number	*Number*	*Per cent*	*Number*	
Drill	88.5	49.0	55.4	6.0	Damping off.
Broadcast	85.5	49.8	58.2	13.5	Weeding.

The relative size and development of the plants from the two methods are summarized in Table 21. The stock was nearly identical in size, weight, and in the very important top-root ratio. There is a tendency for the crowding in the drills to stimulate height growth, but no definite advantage appears in favor of either method.

Table 21.—*Comparative development of 1–0 western yellow pine from seed sown, drill and broadcast*

Method of sowing	Length			Weight			Top-root ratio
	Top	Roots	Total	Top	Roots	Total	
	Inches	*Inches*	*Inches*	*Gram*	*Gram*	*Gram*	
Drill	3.4	8.0	11.4	0.330	0.132	0.462	2.5
Broadcast	3.1	8.0	11.1	.341	.137	.478	2.5

Taking the items of preparing beds, sowing, weeding, cultivating, and lifting as a unit, the difference in cost between the two methods was very slightly in favor of drill sowing, because of the greater expense of weeding the broadcast-sown beds.

Either drill sowing or broadcasting the seed seems to give essentially the same results.

KIND OF MULCH

Two sorts of mulch for seed beds have been tried—pine needles (always available at the cost of collection) and burlap. Experiments carried out at Pilgrim Creek nursery were repeated for each species, with essential similarity of conclusions for both trials. The results of each test are given in brief under the several species.

WESTERN YELLOW PINE

The effect of the two kinds of mulch on germination and production of western yellow pine are summarized in Table 22. In rapidity

TABLE 22.—*Rapidity of germination of western yellow pine seed and density of seedlings under different kinds of mulch*

Mulch	Germination period			Plants per square foot
	Started	50 per cent	Ended	
	Days	*Days*	*Days*	*Number*
Burlap	12	31	52	489
Pine needle	17	45	67	460

and completeness of germination the burlap mulch displays a consistent superiority over the other. Also in size and quality of stock the burlap mulch proved superior to pine needles. (Table 23.) The cost of raising seedlings under burlap per square foot of seed bed proved to be about 10 per cent less than for pine needles, chiefly because of the cost of careful removal of the pine needles from seed beds after germination had started.

TABLE 23.—*Comparison of quality of western yellow pine seedlings and transplants from seeds sown under different kinds of mulch*

Mulch	1–0 seedlings			1–1 transplants		
	Length of top	Length of root	Quality estimated	Length of top	Length of root	Quality estimated
	Inches	*Inches*	*Per cent*	*Inches*	*Inches*	*Per cent*
Burlap	2.2	12.1	100	2.9	17.1	100
Pine needles	1.1	10.0	80	2.5	16.5	85

JEFFREY PINE

Tests with Jeffrey pine gave results similar to those for western yellow pine. On the average, germination started 9 days earlier under burlap than under pine needles and was completed 7 days sooner; 50 per cent of the total germination appeared 12 days sooner and the total germination was 7 per cent greater. In quality and size of stock also the results for Jeffrey pine were similar to those already enumerated for western yellow pine.

SUGAR PINE

Seed of sugar pine sown in the spring in both the tests gave pine needles some superiority over burlap. The germination started five days earlier under burlap, but the final germination, though consistently low, was about 60 per cent greater under the pine needles. In quality of stock produced and in size of stock there was no difference between the two lots, either as seedlings or as transplants. The results were not satisfactory, because of spring instead of fall sowing, but indicated a slight difference in favor of pine needles.

DOUGLAS FIR

Duplicate experiments with Douglas fir indicated clearly the superiority of burlap as a mulch, in that germination started 2 days earlier, was completed in the same time, 50 per cent of germination appeared 17 days earlier, and the total germination was 12 per cent greater. In quality and size of stock the burlap also proved better.

WHITE FIR

The tests with white fir also gave evidence of the superiority of burlap mulch, in that germination started 6 days earlier and was completed 18 days earlier, 50 per cent of total germination appeared 14 days earlier, and total germination for both was nearly the same, with needles showing a very slight advantage. Quality and size of stock were nearly identical for both lots, but in general, burlap mulch appears to give better results than pine needles.

INCENSE CEDAR

With spring-sown seed of incense cedar the burlap mulch displayed consistent superiority, in that germination started 3 days earlier, was completed 10 days earlier, 50 per cent of total germination appeared 10 days earlier, and total germination was 70 per cent greater than for the pine-needle mulch. In quality of stock incense cedar under burlap mulch showed superiority of the same magnitude as did yellow and Jeffrey pines.

SUMMARY

For all species except sugar pine, for which the data are unsatisfactory, burlap mulch appears to be superior to needle mulch in rapidity of starting and completing germination and in number of seedlings germinated. It also produces a better quality of stock. In spring sowing the thickness of the pine-needle mulch, as compared to burlap, appears to prevent soil temperature from rising as rapidly as it might and hence it delays germination. The greater total production under burlap is probably due in part to the unavoidable loss of seedlings in removing the pine-needle mulch. On the whole, burlap remains the more satisfactory mulch for seed beds.

SHADING

The proper season for sowing, the depth to sow, and most of the other requirements that have been discussed are likely to be fairly uniform for the entire range of species, but the question of shading is intimately connected with the local climate of the nursery. For this reason the results obtained in the shading tests must be considered to apply only to local or very similar conditions.

WESTERN YELLOW PINE

Three separate nursery tests were made of the proper shading for western yellow pine, but as they agree substantially, only the average values will be given.

The seedlings were grown under full light, one-fourth shade and one-half shade. The usual low shade frames were used, the shade being applied when the germination was well started. For all three lots the rate and course of germination were practically the same. At the end of the germination period the half-shade bed had the most plants and the open bed the least. This relationship was due entirely to mortality from excessive heat.

From this point until the end of the season the losses varied directly with the degree of shade, so that in November the relative positions were reversed and were as indicated in Table 24. With practically equal weights and lengths for all lots (Table 25) the unshaded stock attained the best top development. The half-shaded stock was especially tall and spindling, as shown in Figure 11. The result of shading appears to be, in general, a greater length of top and shorter roots, owing to the decrease in transpiration. Thus it is evident that in the total number produced, percentage of firsts, and top-root ratio, the unshaded stock makes the best showing. Growing stock without shade is of course a distinct advantage in nursery economy.

TABLE 24.—*Quantity and grading of seedlings and transplants of different species subjected to various degrees of shade in the seed bed*

Species	Degree of shade	Seedlings[1]			Transplants[2]		
		Total per foot	First-class seedlings per foot		Mortality	Firsts	Seconds
		Number	*Number*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Western yellow pine	None	116	77	66	4	89	7
	One-fourth	112	65	58	6	88	6
	One-half	96	51	53	7	82	11
Jeffrey pine	None	69	47	68	3	90	7
	One-fourth	66	35	53	6	83	11
	One-half	80	48	60	11	80	9
Sugar pine	One-third	18	10	56	8	86	6
	One-half	22	12	55	5	86	9
	Two-thirds	26	13	50	12	80	8
Douglas fir	One-third	18	10	56			
	One-half	36	16	44			
	Two-thirds	22	10	45			
White fir	One-third	36	16	44			
	One-half	59	20	34			
	Two-thirds	47	11	23			
Incense cedar	None	21	18	86			
	One-fourth	23	20	87			
	One-half	4	3	75			

[1] Seedlings of western yellow pine, Jeffrey pine, and incense cedar are 1–0 stock; those of the other species are 2–0 stock.

[2] Western yellow pine and Jeffrey pine transplants are 1–1 stock; Sugar pine are 2–1 stock.

TABLE 25.—*Comparative development of seedlings and transplants of various species under different degrees of shade in the seed bed*

Species and age class	Degree of shade	Length			Weight			Top root ratio
		Top	Roots	Total	Top	Roots	Total	
		Inches	*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	
Western yellow pine:	None	3.3	7.2	10.5	0.37	0.16	0.53	2.31
1–0 stock	One-fourth	3.7	6.5	10.2	.37	.13	.50	2.85
	One-half	4.2	6.3	10.5	.42	.14	.56	3.00
	None	3.5	11.2	14.7	2.97	1.34	4.31	2.22
1–1 stock[1]	One-fourth	3.9	9.2	13.1	3.06	1.25	4.31	2.45
	One-half	4.5	9.0	13.5	3.37	1.16	4.53	2.91
Jeffrey pine:	None	3.8	7.5	11.3	.98	.34	1.32	2.88
1–0 stock[2]	One-fourth	3.8	7.0	10.8	.83	.23	1.06	3.61
	One-half	3.7	7.5	11.2	.88	.30	1.18	2.93
	None	3.0	10.0	13.0	3.15	1.56	4.71	2.02
1–1 stock[1]	One-fourth	3.6	10.0	13.6	3.40	1.47	4.87	2.31
	One-half	4.2	10.0	14.2	3.14	1.32	4.46	2.38
Sugar pine:	One-third				1.95	1.45	3.40	1.34
2–1 stock[3]	One-half				2.54	1.68	4.22	1.51
	Two-thirds				2.51	1.76	4.27	1.43
Douglas fir:	One-third	4.8	6.0	10.8	1.31	.47	1.78	2.79
2–0 stock[4]	One-half	5.0	5.9	10.9	.92	.28	1.20	3.29
	Two-thirds	5.8	5.7	11.5	.96	.30	1.26	3.20
White fir:	One-third				.57	.24	.81	2.38
2–0 stock[4]	One-half				.72	.23	.95	3.13
	Two-thirds				.56	.22	.78	2.55
Incense cedar:	None				4.31	1.36	5.67	3.17
1–1 stock	One-fourth				4.33	1.54	5.87	2.81
	One-half				3.18	.85	4.03	3.74

[1] Average of 30 plants for each lot.

[2] Average of 50 plants for each lot.

[3] Average of 12 plants for each lot

[4] Average of 25 plants for each lot. For data on development of transplants see Table 27.

The results of tests of this same stock made in the transplant bed a year later are also indicated in Tables 24 and 25. The difference in quantity and quality of stock are not so evident but still favor perceptibly the unshaded plants, which have a lower mortality and a greater percentage of firsts than the other lots. The total weights are practically the same for all lots, but the top-root ratio indicates a better balance in the unshaded stock. The tendency of shaded plants to produce tall spindling tops still persists after transplanting, as does also the relatively weak root system.

Field survival of shaded western yellow pine was studied in 1915 and 1916, each lot being represented by two plots of 100 plants each, one plot of fall planting and one of spring planting. The plots were contiguous and represented as nearly as possible identical site conditions. The planting in all 12 plots was done by one man. After two years (Table 26) the unshaded stock had the highest survival in both series. In average survival the shaded plots came out about the same. Measurements for height growth made after two years gave identical values for all lots, showing no advantage for the unshaded plants in this respect. The unshaded plants have a definite superiority in yield per unit of area, cost per surviving plant, and survival in the field.

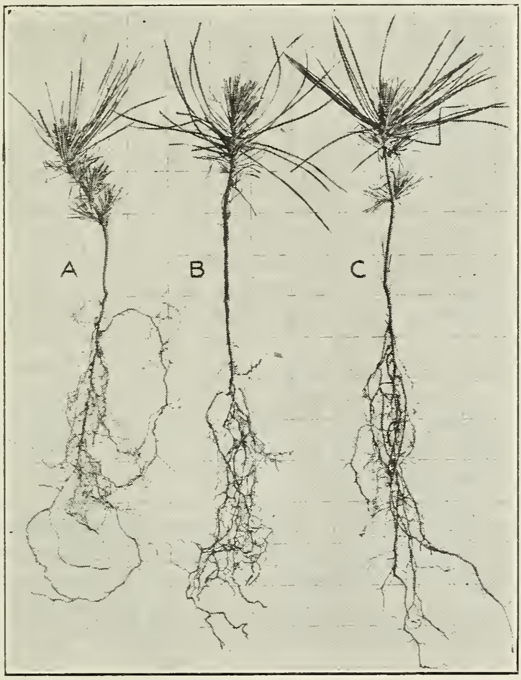

FIGURE 11.—Western yellow pine seedlings under three different degrees of shade: A, none; B, one-fourth; C, one-half. Ground lines form 1-inch squares

TABLE 26.—*Field survival of plants from seed beds receiving various degrees of shade*

Species	Degrees of shade	Survival 1915 series	Survival 1916 series	Average survival
		Per cent	*Per cent*	*Per cent*
Western yellow pine	None	75	38	56
	One-fourth	36	32	34
	One-half	41	29	35
Jeffrey pine	None	76	62	69
	One-fourth	53	61	57
	One-half	50	54	52
Sugar pine	One-third			9.3
	One-half			10.3
	Two-thirds			11.7
Incense cedar	None			44
	One-fourth			38
	One-half			35

JEFFREY PINE

Two separate nursery tests of shading were made with Jeffrey pine with practically identical results. The average values for the two tests are given in Tables 24 and 25. No shade, one-fourth shade, and one-half shade were applied as for western yellow pine. The rate and course of germination were found to be essentially the same for all degrees of shade. Half shade produced the largest number of plants at the end of the season, with the other two lots about equal. The percentage of firsts, however, is highest for the unshaded plants.

In comparative development no striking differences appeared. The unshaded plants and those half shaded are very similar in proportional size and in weight ratio. In total weight the unshaded plants lead. Here, as in the grading of the stock, the ¼-shaded plants seem out of line with the others.

After a year in the transplant bed, the unshaded plants came out definitely in the lead in low mortality, and high percentage of firsts. This lead was substantiated by a favorable top-root ratio. The tendency of shade was notably to increase heights and to produce tall, spindling plants. In general, the unshaded stock appears to fare best and is of course the most economical to produce in the nursery.

Tests of survival in the field were developed identically in number of plots and other particulars for Jeffrey pine as for western yellow pine. In both series the order is the same (Table 26) and follows that of weight ratio of transplant stock. The evidence points fairly certainly to the conclusion that unshaded stock gives the highest survival.

SUGAR PINE

In the shade tests of sugar pine, one-third, one-half, and two-thirds shade were employed. Previous experiments had shown that because of the heat of the California summer it is impossible to grow sugar pine in the open. At the end of the first year in the nursery, germination under one-half shade equaled that under two-thirds shade. One-third shade gave a much lower result. At the end of the second year in the seed bed heavy losses had been suffered. In relative survival (Table 24) the total number of seedlings per foot varied directly as the degree of shade, whereas the percentage of firsts varied inversely.

In size and development only minor differences showed up in the 2–0 stock. The top-root ratios favored the lighter shadings, being 2.43 for one-third shade, 2.90 for one-half, and 3.15 for two-thirds, in the same order as for the other pines.

After a year in the transplant beds only minor differences were apparent, favoring slightly the stock under the lighter degrees of shade, with the exception that ⅓-shaded stock appeared to be somewhat inferior to the others in total weight.

Duplicate tests of survival in the field were made on the experiment station grounds, and single tests on the Shasta National Forest, but all suffered heavy losses. The average survival for one-third, one-half, and two-thirds shaded (Table 26) slightly favored the heavier shadings.

The results with sugar pine do not point clearly to any one method as the best. As nursery economy urges the use of standard shade frames, giving one-half shade, the desirability of one-half shade for sugar pine is indicated. Repeated efforts to grow sugar pine without shade have failed.

DOUGLAS FIR

As with sugar pine, preliminary work with Douglas fir indicated clearly that some degree of shade in the seed beds was imperative, and therefore the tests given were for one-third, one-half, and two-thirds shade.

In total number of seedlings and number of first-grade plants after two years in the seed beds (Tables 24 and 25) one-half shade has the advantage, but in comparative development ⅓-shaded stock is definitely the heaviest and has the lowest top-root ratio.

Because of previously heavy loss of Douglas fir seedlings in the transplant beds, each lot of seedlings transplanted was divided, one-half receiving no shade, and the other half being given one-half shade. After the first year the production figures were on the average 88 per cent of firsts for both shaded and unshaded lots with only trifling variations.

Shade in the transplant beds appears to increase the total weight an average of 29 per cent (Table 27), the greater part of the increase being in the weight of the roots. The weight of the top increases consistently with the total shade received during the life of the plant. In the unshaded transplant beds top-root ratio distinctly favors the ⅔-shaded seedlings, whereas in the transplant beds receiving one-half shade the most favorable ratio is for the ⅓-shaded seedlings. One-half shaded seedlings fare badly in both instances. Judging again by top-root ratios, one-half shade in the transplant bed is preferable to no shade, and in general favors the plants that as seedlings have a good weight ratio.

Field tests made on a very dry site yielded so low a survival (Table 27) that the results hardly indicated more than a tendency to favor the plants with lowest ratios. Plants one-third and one-half shaded had the best survival.

TABLE 27.—*Comparative development and field survival of Douglas fir and white fir transplants (2–1 stock) under different degrees of shade in seed beds and transplant beds*

DOUGLAS FIR

Degree of shade	Weight			Top-root ratio	Average ratio	Field survival
	Top	Roots	Total			
	Grams	*Grams*	*Grams*			*Per cent*
One-third in seed bed, none in transplant bed	2.27	1.64	3.91	1.38	1.18	0
One-third in seed bed, one-half in transplant bed	3.07	3.11	6.18	.99		8
One-half in seed bed, none in transplant bed	3.09	1.04	4.13	2.97	2.21	0
One-half in seed bed, one-half in transplant bed	3.71	2.55	6.26	1.45		0
Two-thirds in seed bed, none in transplant bed	4.47	3.97	8.44	1.13	1.18	3.5
Two-thirds in seed bed, one-half in transplant bed	4.90	4.00	8.90	1.22		4.5
Average all	3.58	2.72	6.30	1.32	--------	2.6
Average unshaded transplants	3.28	2.22	5.49	1.48	--------	1
Average one-half-shade transplants	3.89	3.22	7.11	1.21	--------	4

WHITE FIR

Degree of shade	Top	Roots	Total	Top-root ratio	Average ratio	Field survival
One-third in seed bed, none in transplant bed	1.00	.67	1.67	1.49	1.65	2
One-third in seed bed, one-half in transplant bed	1.32	.73	2.05	1.81		0
One-half in seed bed, none in transplant bed	1.32	.69	2.01	1.91	1.72	0
One-half in seed bed, one-half in transplant bed	1.65	1.08	2.73	1.53		8
Two-thirds in seed bed, none in transplant bed	1.39	.93	2.32	1.49	1.64	4
Two-thirds in seed bed, one-half in transplant bed	1.32	.74	2.06	1.78		0
Average all	1.33	.81	2.14	1.64	--------	2
Average no shade	1.24	.76	2.00	1.63	--------	2
Average one-half shade	1.43	.85	2.28	1.68	--------	2

In general, the results for Douglas fir indicate that one-third shade in the seed bed is preferable to one-half shade; whereas, in the transplant beds one-half shade is very much better than no shade. In the transplant beds and in field tests alike results favor those plants having the best top-root ratios. Although shade in transplant beds is expensive, the better results appear to justify the practice where Douglas fir is grown under conditions similar to those in this experimental work. Because two-thirds shade gives more consistent results than one-third shade, future shading on two-thirds and one-half basis is indicated.

WHITE FIR

In the seed beds one-third, one-half, and two-thirds shade were used, as for Douglas fir and sugar pine. The highest percentage of firsts was produced under one-third shade, but the highest number of firsts, as well as the largest total number of seedlings, was produced under one-half shade. Losses in the lightly shaded bed were severe. No differences of any importance in lengths was noted, but there were considerable differences in weight. (Table 25.) The half-shaded seedlings are decidedly the heaviest, though the extra weight is at the top and consequently gives a less favorable weight ratio.

As with the Douglas fir seedlings, transplanting was made in two lots, one receiving no shade and the other receiving one-half shade for one year. In percentage of firsts the half-shaded transplants were only slightly in the lead. Comparative development, as shown in Table 27, indicates that shade of transplant beds increases the total weight of the lightly shaded seedlings by 30 per cent, this weight being fairly equally distributed between roots and tops. The half-shaded seedlings maintain the same lead in weight as 2–1 stock that they had as 2–0 stock. The shading of the transplant bed apparently had little definite effect on the weight ratios. Using the weight ratios as an index of the probable survival of the individual lots, the order of preference is as follows: ½ plus ½, ⅔ plus 0, ⅓ plus 0, ⅔ plus ½, ⅓ plus ½, ½ plus 0.

Survival in the field tests was unfortunately very low because a site was employed for the field planting which was too dry for white fir. The results check very closely with the nursery tests, however. Plants with ratios higher than 1.6 were total failures.

In general, it may be said that one-half shade was most successful in the seed beds, and that this advantage was improved by one-half shade in the transplant beds. Although shading transplant beds is an awkward and expensive practice, it is advisable under climatic conditions similar to those experienced in the tests. There is no indication that the theory is tenable that nursery stock of Douglas fir or white fir should be subjected to hardships to bring out "the survival of the fittest."

INCENSE CEDAR

The same shading was applied to incense cedar as to western yellow pine and Jeffery pine—namely, no shade, one-fourth and one-half. In the seed beds the half-shaded seedlings were only about one-fifth the number of those having no shade or one-fourth shade. The very heavy losses were due to damping off, which has caused trouble in other experimental work for this species. Table 24 shows that there is very little to choose between no shading and one-fourth shading. Measurement of several lots showed very little difference in length and weight. Some shaded stock was slightly heavier.

After a year in transplant beds, the percentages of firsts were, respectively, 84, 86, and 90 for the unshaded, ¼-shaded, and ½-shaded beds. Length of tops showed only minor differences, but the weights as given in Table 25 are more significant; ½-shaded plants average least in weight and have the poorest ratio; ¼-shaded plants are heaviest and have the best ratio, although the advantage over those unshaded is only slight.

Duplicate field tests were made at Feather River and single field tests on the Shasta National Forest. The average survivals for unshaded, one-fourth shaded, and one-half shaded plants were 44, 38, and 35 per cent, respectively. This order of survival was the same in each of the individual tests.

In general, the tests with incense cedar favor very slightly the unshaded seedlings as 1–0 stock, and more decidedly the ¼-shaded seedlings as transplants. As the unshaded plants have the highest survival in the field and because of the greater ease and economy in the nursery, no shade is indicated as the preferred treatment.

SUMMARY

General results may be briefly summarized. With respect to the amount of shade to be employed, two general groups of species must be recognized: (1) The hardy species—western yellow pine, Jeffrey pine, and incense cedar; and (2) the more sensative species—sugar pine, Douglas fir, and white fir.

The hardy species are produced as well under no shade as under shade, and the pines especially have a great deal better development when shade is not applied. The more susceptible species experience a heavy loss unshaded or even with light shade, and in general do better if shade is supplied in the transplant beds. The best development of these species is generally found under one-half shade.

Field tests show that survival almost invariably follows the indications of the top-root ratios.

Correct shading practice is essentially a local question and must be settled for each nursery individually. In general, it appears that the more susceptible species should not be raised in nurseries located outside of their natural range.

WATERING AND CULTIVATION

The study of watering and cultivation of seed beds has many inherent difficulties. There is an almost infinite number of combinations which may be used, and proper watering is so intimately related to fluctuation of local weather conditions that hard and fast rules are likely to be less satisfactory than a day-to-day study of soil-moisture conditions in beds. The tests here described were designed to answer only one phase of the general question, namely, whether cultivation can take the place of watering to any considerable extent.

The tests were made in pairs for all the species. In each instance the beds were treated alike through the germination period. Thereafter one bed was watered frequently (the usual nursery practice) and the other cultivated often and watered only when necessary, the theory at that time being that cultivation after watering would form a dust mulch and conserve the soil moisture.

WESTERN YELLOW PINE

In the cultivated bed of western yellow pine the loss of seedlings from the end of the germination period to the close of the first season was very much heavier than in the watered bed, as Table 28 shows. The watered stock was somewhat larger, with a better root system than the other. The most striking differences were in the total number and the number of firsts produced.

TABLE 28.—*Grading of seedlings after watering and cultivation of beds*

Species and age class	Treatment	Seedlings per foot		
		Total	First-grade	
		Number	*Number*	*Per cent*
Western yellow pine, 1–0 stock	Watered	41.0	24.0	59
Do	Cultivated	29.0	18.0	62
Sugar pine, 1–0 stock	Watered	34.5	19.0	55
Do	Cultivated	26.0	11.4	44
White fir, 2–0 stock	Watered	48.0	14.0	29
Do	Cultivated	34.5	10.0	29
Incense cedar, 1–0 stock	Watered	54.0	31.6	59
Do	Cultivated	40.0	24.0	60

After transplanting, the previous treatment was continued, the lot watered in the seed bed being watered 105 times in the transplant beds, the other 62 times, plus 41 cultivations. When the 1–1 stock was lifted striking differences were found, as shown in Tables 29 and 30. Loss by death was much less for watered than for cultivated stock. At the same time a larger percentage of firsts was produced for the watered plants, and these plants were taller and heavier and had a much better weight ratio. On the basis of equal quantities of seed and equal seed-bed area, the watered plants produced 92 per cent more first class 1–1 stock than did the cultivated plants.

TABLE 29.—*Grading of transplants after watering and cultivation of beds*

Species and age-class of stock	Treatment	Dead	Firsts	Seconds and culls
		Per cent	*Per cent*	*Per cent*
Western yellow pine (1,125 plants), 1–1 stock	Watered	4	84	12
Do	Cultivated	13	59	28
Jeffrey pine (1,475 plants), 1–1 stock	Watered	4	86	10
Do	Cultivated	23	47	30
Sugar pine (260 plants), 2–1 stock	Watered	2	91	7
Do	Cultivated	5	77	18
Douglas fir (260 plants), 2–1 stock	Watered	3	91	6
Do	Cultivated	7	74	19
White fir (260 plants), 2–1 stock	Watered	5	85	10
Do	Cultivated	9	72	19
Incense cedar (575 plants), 1–1 stock	Watered	0	95	5
Do	Cultivated	4	90	6

TABLE 30.—*Comparative development of transplants of various species after watering and cultivation of beds*

Species, age class, and manner of treatment	Length			Weight			Top-root ratio
	Top	Roots	Total	Top	Roots	Total	
	Inches	*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	
Western yellow pine (1–1 stock): [1]							
Watered	5.5	7.5	13.0	5.13	4.20	9.33	1.22
Cultivated	4.0	6.0	10.0	4.22	2.20	6.42	1.92
Jeffrey pine (1–1 stock): [2]							
Watered	6.0	9.0	15.0	5.32	2.00	7.32	2.66
Cultivated	4.5	7.5	12.0	2.55	1.10	3.65	2.32
Sugar pine (2–1 stock): [1]							
Watered	5.0	8.5	13.5	1.67	1.38	3.05	1.21
Cultivated	4.6	8.5	13.1	1.51	.94	2.45	1.61
Douglas fir (2–1 stock): [1]							
Watered	6.7	10.0	16.7	3.10	2.14	5.24	1.45
Cultivated	6.2	10.0	16.2	2.58	1.65	4.23	1.56
White fir (2–1 stock): [3]							
Watered	4.0	10.0	14.0	1.35	.79	2.14	1.71
Cultivated	3.6	10.0	13.6	1.17	.62	1.79	1.89
Incense cedar (1–1 stock): [1]							
Watered	4.9	9.7	14.6	2.18	.80	2.98	2.72
Cultivated	4.9	8.7	13.6	2.02	.84	2.86	2.40

[1] Average of 10 plants in each class. [2] Average of 20 plants in each class. [3] Average of 15 plants in each class

Duplicate plots of 100 plants each were established on the experiment-station grounds in the fall of 1914 and spring of 1915. After two years the survival was, on the average, 75 per cent for watered stock and 66.5 per cent for cultivated.

The relative growth also definitely favors the watered stock. From measurements of 50 plants from each lot the figures in Table 31 were derived. The absolute growth was over twice as great for watered as for cultivated stock. Moreover the percentage of growth was greater for the watered stock.

TABLE 31.—*Comparative growth in field of western yellow pine after watering and cultivation* [1]

Treatment	Height—		Net growth in field	
	When planted	After two years		
	Inches	*Inches*	*Inches*	*Per cent*
Watered	5.5	8.0	2.5	45
Cultivated	4.0	5.2	1.2	30

[1] Figures are derived from measurements of 50 plants from each lot.

If further proof is necessary, study of the comparative costs furnishes it. Starting with 4 by 12 foot seed beds, and using figures derived from experiment, these costs are expressed finally in Table 32 in terms of survival of plants in the field. As seedlings, transplants, and field plants, the cost is always greater for the cultivated plants, the final cost of the surviving plants in the field being 27 per cent higher than for watered stock.

TABLE 32.—*Comparative costs per thousand of watered and cultivated western yellow pine (1–1 stock, field planted) on the basis of firsts in seed and transplant beds and survivors of one year in the field*

Expense item at various stages of development	Cost for—	
	Watered plants	Cultivated plants
Seedlings:		
Preparation of bed	$0.40	$0.40
Seed	.20	.20
Care	.40	.50
Total	1.00	1.10
Cost per 1,000 firsts produced (1–0)	1.09	1.59
Transplants:		
Preparation of bed	.50	.50
Transplanting	1.00	1.00
Care	.98	1.43
Total	2.48	2.93
Cost per 1,000 firsts produced (1–1)	2.75	4.53
Field plants:		
Labor of planting	7.50	7.50
Cost per 1,000 surviving plants	9.92	11.35
Summary:		
Seedlings	1.09	1.59
Transplants	2.75	4.53
Field plants	9.92	11.35
Total cost per 1,000 living plants	13.76	17.47

In number of firsts produced as 1–0 and 1–1, in size and development of firsts, in survival in field, in rate of growth, and in cost per living plant, watered stock proves superior to cultivated. The theory that cultivation can take the place of water to any considerable extent, and produce as hardy stock, does not work out in practice. Of course, this one test is not in any sense a comprehensive study of the whole range of possibilities. It does, however, show very clearly that for production of hardy stock abundant water is better than light watering and cultivation. The principle established is an important one, even though the actual amount and frequency of watering at a given nursery is a matter of common sense rather than of rigid rules.

JEFFREY PINE

In the seed beds both lots of Jeffery pine produced practically the same total number of plants and number of firsts per foot of drill, with comparatively little difference in size or development. After a year in transplant beds, the plants differed greatly, both in grading (Table 29) and in development (Table 30) of the surviving plants. The evidence is clear that watered stock is superior to cultivated in lower mortality, greater percentage and number of firsts produced, and larger and better developed stock resulting. The slight difference in ratio in favor of the cultivated stock appears likely to be more than balanced by the greater weight of the watered stock.

The survival after two years in the field was, on the average, 64 per cent for the watered stock and 62 per cent for the cultivated stock. Watered stock made four and one-half times as much absolute growth after planting, as measured on 50 plants, and three times as much percentage growth.

Since final survival in the field is practically the same for both, cost per surviving plant is an important point. Without repeating the detailed figures, such as have been given for western yellow pine, it may be said that cost per living plant is 20 per cent greater for cultivated than for watered stock. Though at no stage are the differences so striking as for western yellow pine, it is clear that cultivation does not take the place of watering.

SUGAR PINE

Watering was the same for both lots of sugar pine till the end of May, when it was reduced for one lot. In all, one bed was watered 85 times, and the other 46 times plus 28 cultivations. The yield at the end of the year, as shown in Table 28, shows clearly the superiority of watering, since that treatment produced 67 per cent more firsts than did cultivation. The watered seedlings averaged one-half of an inch taller than the others, and with the same weight ratio were also slightly heavier.

After a year in the transplant beds with treatment differentiated as before, the stock was lifted for planting and examined. The increase in production already noted in the seed beds was paralleled in the transplant beds (Table 29), and in comparative development (Table 30) notable differences also appeared. The greater weight of the stock and the lower top-root ratio both point to abundant watering as the best method of raising sugar pine.

In the field tests, which were carried out in duplicate at Feather River and singly on the Shasta National Forest, the survival was uniformly low, owing to the combination of unfavorable sites and a very dry season, so that average survival for watered stock was 13 per cent and for cultivated stock 8.5 per cent. Here, as in other tests with this and other species, a study of the weight ratio of the stock provided an excellent forecast of its survival in the field.

Sugar pine, in quantity and quality of stock produced, and in survival under field conditions, does better with abundant watering in the nursery, rather than lighter watering and frequent cultivation.

DOUGLAS FIR

The germination of Douglas fir the first year was identical for both beds, but the stock was left for two years in the seed bed and under the same treatment because of the small size of the 1–0 stock. As 2–0 stock, there was the same number of plants and number of firsts per foot of drill for both, but in size and development the watered stock was better. The tops averaged one-half of an inch longer, and the weight, though with the same ratio, was 10 per cent greater. The differences are relatively slight but favor the watering treatment.

After a year in the transplant beds, the stock was lifted for planting and again examined. (Table 29.) The decidedly greater yield of the watered stock was evident, as were the differences in development shown in Table 30. The difference in weight ratio is comparatively slight, but the greater weight of the stock from the watering treatment indicates its superiority over that from the cultivation treatment.

Field tests were made in duplicate at Feather River and singly on the Shasta National Forest. Survival was low in these plantings also because of the combination of unfavorable sites and a very dry season, the averages being 8 per cent for watering and 3 per cent for cultivation.

In general, the watering treatment showed superiority over the cultivation treatment.

WHITE FIR

Tests for this species were run at the same time as for sugar pine and Douglas fir, and as in those tests the stock was kept in the seed bed for two years. The germination the first year was 8 per cent greater for watered than for cultivated stock, and loss the second year was much heavier for the cultivated, as 2–0 production figures show. (Table 28.) A material difference in size and development was also found. (Table 33.) That the watered stock was very decidedly larger and better balanced is indicated by the ratio. In seed beds watering produced more and better plants per unit area at less cost than did cultivation.

In the transplant beds (Tables 29 and 30) the greater production of first-class stock from the watering treatment is evident, as is also the more favorable comparative development. The greater weight and lower ratio of the stock point to watering as the better method of treatment.

INCENSE CEDAR

The germination of incense cedar was slow, and the reduction of water in July resulted in a drop in germination in the cultivated bed. Table 28 shows the production at the end of the year, and Table 33 the development of the two lots. The differences, though comparatively slight, are in favor of watering treatment. Somewhat greater size and lower ratio tend to show that the watered stock will be superior to that under cultivation.

TABLE 33.—*Comparative development of white fir and incense cedar seedlings after watering and cultivation* [1]

Species and manner of treatment	Length			Weight			Top-root ratio
	Top	Roots	Total	Top	Roots	Total	
White fir (2–0 stock):	*Inches*	*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	
Watered	3.7	5.0	8.7	0.70	0.26	0.96	2.69
Cultivated	3.0	4.5	7.5	.47	.16	.63	2.94
Incense cedar (1–0 stock):							
Watered	3.7	6.3	10.0	.32	.12	.44	2.67
Cultivated	3.5	6.2	9.7	.27	.09	.36	3.00

[1] Averages of 25 plants in each class.

After a year in the transplant beds with differentiation of treatment continued, the watered 1–1 stock showed 95 per cent of firsts, the cultivated 90.5 per cent. In comparative development, little difference appeared, the watered stock being slightly heavier than the cultivated, but with a ratio somewhat greater. Little difference in field survival was anticipated. Duplicate tests in the field were made at Feather River, and a single test on the Shasta National Forest. Average survivals were 28 per cent for watered stock, and 23.5 per cent for cultivated stock.

As with the other species, watering produced more first-class stock of better quality and a higher field survival than did cultivation. The cost per living plant in the field was 23 per cent greater for the cultivated than for the watered stock.

SUMMARY

Although the results of this group of studies are reasonably clear and definite, they cover only one phase of the broad question of correct treatment of seedings and transplants. They indicate that with a clay soil which bakes and cakes readily cultivation does not take the place of watering; but the question of the optimum amount of water has scarcely been touched, except in so far as a day-to-day study of the appearance of the plants has led to the development of a flexible watering schedule which has resulted in the production of good stock.

The problem of correct watering is certainly one of the most important phases of nursery practice, and is one which must be solved for each nursery separately. Cultivation, while a failure as a substitute for watering, nevertheless has a definite function in nursery technic in keeping the topsoil loose and free from weeds.

Correct watering is more a question of common sense than of definite hard-and-fast rule or schedule.

The major conclusion from the group of experiments is this: Abundant watering, particularly in seed beds, is essential if thrifty, properly developed stock is to be grown. Efforts to cut down water on the theory of thereby developing hardy stock are likely to result in failure.

TABLE 34.—*Summary of conclusions in nursery practice*

Item	Western yellow pine	Jeffrey pine	Sugar pine	Douglas fir	White fir	Incense cedar
Average number of seeds per pound.	10,000	4,000	2,200	35,000	16,000	16,000.
Average good seedlings per pound of seed.	5,000	2,000	500	9,000	4,000	3,200.
Preliminary treatment of seed	None	None	Sulphuric acid for spring sowing.	None	None	None.
Season to sow	Early spring	Early spring	Fall	Early spring	Fall	Fall.
Amount to sow for 1–0 stock	70 to 100 per linear foot	60 to 80 per linear foot	60 to 80 per linear foot	Too small to transplant.	Too small to transplant.	60 to 80 per linear foot.
Amount to sow for 2–0 stock	30 per linear foot	30 to 35 per linear foot	30 to 35 per linear foot	30 to 40 per linear foot	50 to 60 per linear foot	35 to 40 per linear foot.
Depth to sow, inch	½ (¼ to ½)	½ (⅜ to ⅝)	¾	⅛ to ¼	⅛	½.
Drill or broadcast sowing	Optional	Optional	Optional	Optional	Optional	Optional.
Kind of mulch	Burlap	Burlap	Burlap	Burlap	Burlap	Burlap.
Shading for seed beds	None	None	One-third to one-half shade.	One-third to one-half shade.	One-third to one-half shade.	None.
Shading for transplants	None	None	None	do	do	None.
Protection of seedlings from spring frost.	Advisable	Advisable	Essential	Essential	Essential	Advisable.
Protection of seedlings from fall frost.	Unnecessary	Unnecessary	Unnecessary	do	do	do
Cultivation	Only to degree required to control weeds.	Only to degree required to control weeds.	Only to degree required to control weeds.	Only to degree required to control weeds.	Only to degree required to control weeds.	Only to degree required to control weeds.
Watering	Frequent and abundant watering needed.	Frequent and abundant watering needed.	Frequent and abundant watering needed.	Frequent and abundant watering needed.	Frequent and abundant watering needed.	Frequent and abundant watering needed.
Best age class to plant	1–1 or 1–1–1	1–1 or 1–1–1	2–1	2–1	2–1	1–1.

FIELD-PLANTING EXPERIMENTS

CLASSES OF STOCK

Several years of experimental work in field planting have shown clearly that at least for northern California age of stock in itself means little save that practical limitations in the handling of stock of certain sizes inevitably limit the age of the stock. To attain any significant results, age class of stock must be considered in relation to quality of stock and, as explained in connection with the tests recorded in the earlier sections of this circular, the most satisfactory measure of quality, and apparently also of survival, is the simple ratio of weight of top to weight of root.

Field tests of the best age classes for planting stock were applied to plants of the same six species that figured in the tests already recorded, namely, western yellow pine, Jeffrey pine, sugar pine, Douglas fir, white fir, and incense cedar. The field tests were made in two different years. Grading of stock and planting were all done by one man, and plots were carefully selected for similarity of site conditions.

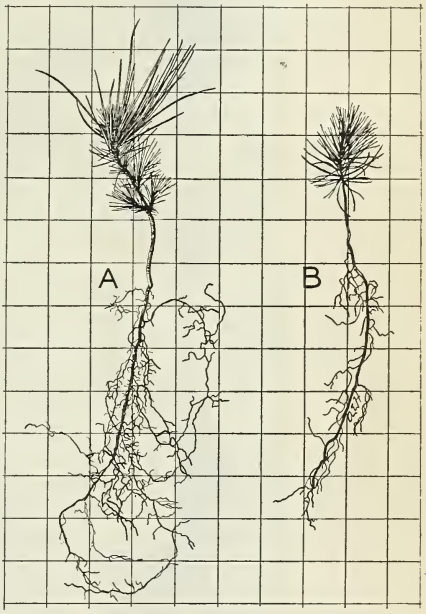

FIGURE 12.—Typical western yellow pine stock; A, 1–1 transplant, B, 1–0 seedling. Ground lines form 1-inch squares

WESTERN YELLOW PINE

AGE CLASSES

Six age classes of western yellow pine stock were tested: 1–0, 2–0, 1–1, 2–1, 1–2, and 1–1–1. Figures 12 and 13 show typical specimens. One-year seedlings (1–0) are small, but with well-developed taproots; they have few lateral roots and their secondary needles are undeveloped. This stock is too small for field planting use under the trying conditions of northern California.

The 2-year seedling stock has a very strongly developed taproot and rather weak laterals. Western yellow pine, if undisturbed for two years, sends the taproot deep into the soil to a supply of moisture independent of that supplied by watering. Thus lateral roots tend to develop poorly.

The 1–1 stock is very good. A year in the transplant bed has resulted in abundant and well-balanced root development, and the top meanwhile has not grown too large. The 2–1 stock is also good, save that the heavy taproot resulting from two years in the seed bed still dwarfs a full development of the laterals. For size of top, the roots are not as strong as might be desired. In 1–2 stock the same difficulty is found; that is, a very strong top developed with comparatively weak lateral roots. During the second growing season the upper lateral roots which are not called on for moisture supply do not develop. The 1–1–1 is easily the best of any age class; double transplanting checks the development both of top and taproot and stimulates the lateral roots.

Table 35 presents data on the size and development of different lots of all the species planted in the 1915 and 1916 series of tests, together with the final survival after three years in the field. Judging solely from values shown, better results might be expected from 1–0 western yellow pine of the 1915 series than from 2–0, and the survival percentages bear this out. In the transplant stock this relationship between top-root ratio and survival is generally maintained but is not entirely consistent. The 1–2 stock has the highest ratio, followed by 1–1, 1–1–1, and 2–1, in the order given; but in survival 1–1–1 proves to be the best.

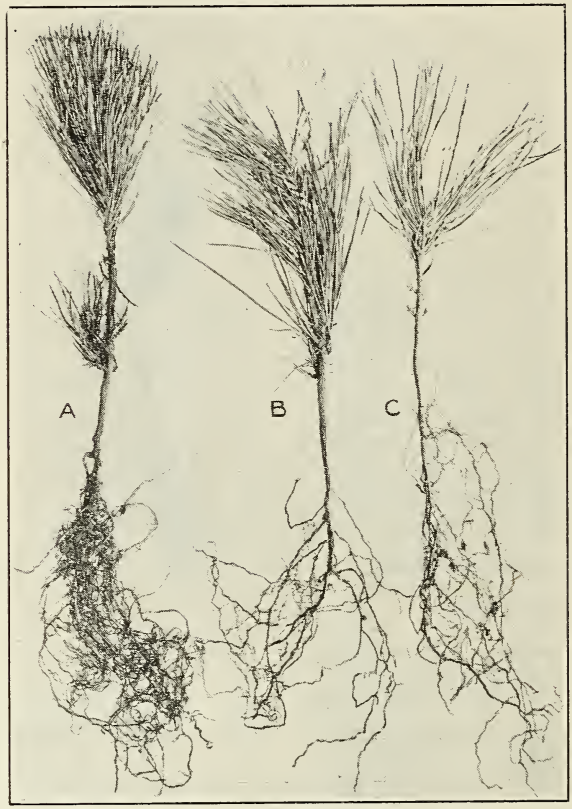

FIGURE 13.—Typical western yellow pine stock: A, 1–1–1; B, 1–2; C, 2–1. Ground lines form 1-inch squares

The data for the 1916 series (Table 35) are somewhat less consistent. However, judging from the ratios, 2–0 appears superior to 1–0 stock, and 1–1–1 is clearly the best of the transplant stock with 1–1 next and 2–1 and 1–2 with high ratios. Survival figures indicate the substantial correctness of this diagnosis.

TABLE 35.—*Quality of different age classes as planting stock, with field survival*

WESTERN YELLOW PINE

Age class	1915 series					1916 series				
	Weight			Top root ratio	Field survival	Weight			Top root ratio	Field survival
	Top	Roots	Total			Top	Roots	Total		
	Grams	*Grams*	*Grams*		*Per cent*	*Grams*	*Grams*	*Grams*		*Per cent*
1–0	0.54	0.26	0.80	2.08	31	0.23	0.10	0.33	2.30	2
2–0	.86	.28	1.14	3.07	6	1.40	.93	2.33	1.51	12
1–1	2.94	1.19	4.13	2.47	82	3.00	1.40	4.40	2.14	38
2–1	8.42	4.88	13.30	1.73	92	3.44	1.31	4.75	2.63	5
1–2	12.38	4.95	17.33	2.50	78	9.11	3.02	12.13	3.02	4
1–1–1	10.95	4.62	15.57	2.37	99	7.47	3.90	11.37	1.92	55

JEFFREY PINE

Age class	Top	Roots	Total	Top root ratio	Field survival	Top	Roots	Total	Top root ratio	Field survival
1–0	0.85	0.25	1.10	3.40	31	0.50	0.17	0.67	2.94	4
2–0	2.30	.81	3.11	2.84	40	1.80	.97	2.77	1.86	19
1–1	3.33	1.69	5.02	1.97	88	2.96	1.42	4.38	2.08	51
2–1	5.76	2.52	8.28	2.29	72	--------	--------	--------	--------	--------
1–2	12.18	3.00	15.18	4.06	56	11.30	2.88	14.18	3.92	31
1–1–1	8.40	3.50	11.90	2.40	95	5.52	3.45	8.97	1.60	60

SUGAR PINE

Age class	Top	Roots	Total	Top root ratio	Field survival	Top	Roots	Total	Top root ratio	Field survival
3–0	--------	--------	--------	--------	--------	1.48	0.93	2.41	1.59	3
1½–1	--------	--------	--------	--------	--------	1.58	1.14	2.72	1.39	6
2–1	--------	--------	--------	--------	--------	2.19	1.76	3.95	1.24	7

DOUGLAS FIR

Age class	Top	Roots	Total	Top root ratio	Field survival	Top	Roots	Total	Top root ratio	Field survival
2–0	--------	--------	--------	--------	--------	0.27	0.10	0.37	2.70	0
3–0	--------	--------	--------	--------	--------	1.06	.36	1.42	2.94	0
2–1	--------	--------	--------	--------	--------	4.47	3.97	8.44	1.13	4
1–2	--------	--------	--------	--------	--------	1.66	.94	2.60	1.77	1

INCENSE CEDAR

Age class	Top	Roots	Total	Top root ratio	Field survival	Top	Roots	Total	Top root ratio	Field survival
1–0	0.46	0.16	0.62	2.88	14	0.30	0.11	0.41	2.73	2
1½–0	.62	.20	.82	3.10	8	--------	--------	--------	--------	--------
2–0	.77	.26	1.03	2.96	19	1.22	.40	1.62	3.05	8
3–0	--------	--------	--------	--------	--------	--------	--------	--------	--------	48
1–1	2.53	1.19	3.72	2.13	56	4.31	1.36	5.67	3.17	46
1½–1	4.17	1.74	5.91	2.40	41	4.19	1.78	5.97	2.35	24
2–1	9.80	5.17	14.97	1.90	51	4.05	1.80	5.85	2.25	32
1–2	20.32	5.45	25.77	3.73	46	5.66	2.47	8.13	2.29	63
1–1–1	13.05	7.48	20.53	1.74	63	--------	--------	--------	--------	--------

In the average for two years. 1–1–1 was much the best and 1–2 the poorest of all transplants; 1–1 was next to 1–1–1. The much lower survival of the 1916 series was due to the dry year. Relative values are more important than the absolute for present purposes. In general, the ratios of 2.5 and higher for transplant stock are to be regarded with suspicion (speaking for northern California conditions), and for seedlings, ratios of 2.0 and higher.

For most planting areas seedling stock is too uncertain; 1–1 is best for ordinary use, and 1–1–1 for very unfavorable sites. Of the transplant stock, 1–1 is of course the most economical to raise.

QUALITY CLASSES

Quality classes of planting stock are not always identical with age classes. An age class may even contain more than one quality class. Data on quality of western yellow pine, obtained in studying large-scale plantations made in 1916 and 1917 on the Shasta National Forest, indicate within the 1–2 age class three well-marked quality classes. These are:

(1) Plants with very large tops, heavy tap roots, and comparatively few laterals. Such plants come from the ends of the transplant rows where root competition has been light.

(2) Plants with medium-sized tops, typical of the age class.

(3) Plants with small tops and weak root systems. These are usually about the size of the next youngest age class, and developed into inferior stock when transplanted.

The survival after field planting in heavy brush is given in Table 36.

TABLE 36.—*Survival of quality (size) classes within the 1–2 age class of western yellow pine and Jeffrey pine*

Species	Size or quality class	Plants examined	Plants surviving	
		Number	*Number*	*Per cent*
Western yellow pine	Large	748	371	49.6
	Medium	3,078	1,164	37.5
	Small	694	158	22.8
Total		4,520	1,683	37.2
Jeffrey pine	Large	138	61	44.2
	Medium	887	456	51.4
	Small	210	77	36.7
Total		1,235	594	48.1

An important consideration in this connection is the possibility of improving even the poorest transplants by carefully grading the seedlings at the time of transplanting and eliminating the inferior seedlings which, as has already been shown in the discussion of nursery practice, remain undesirable as transplants. When the first-class and inferior seedlings of a single lot of western yellow pine were kept separate in transplanting, and the resulting plants kept separate under similar field conditions, the survival of the firsts was 78 per cent, and of the seconds 36 per cent, or less than half.

JEFFREY PINE

The pictures of the Jeffrey pine stock in Figures 14 and 15 show an even stronger tendency in this species than in western yellow pine to form a very heavy taproot. This is particularly noticeable in stock remaining two years undisturbed, namely, 2–0, 1–2, and 2–1. It it to be expected that such stock with its weak lateral development will attain poor field survival.

In general the relative development of each age class is similar to that for the same class in western yellow pine. (Table 35.) The data on the stock used in the 1915 tests with field survival after three years make this clear. The 1–2 stock had the highest ratio and lowest survival of any transplants, with 2–1, 1–1, 1–1–1 following in order. The ratio of 1–1–1 was higher than for 1–1, but double transplanting so broke up the root system that it represents greater absorbing power. The difference in the total weight of the 2-year classes (2–0 and 1–1) is material.

In the 1916 series survival is lower than for 1915, primarily because of the very dry year. Study of the ratios shows especially striking difference between 1–2 and 1–1–1; 2–0 is better than 1–0, and 1–1 comes next to 1–1–1.

The survival figures confirm prediction and follow those of the 1915 tests. The 1–1–1 is clearly the best, with 1–1 next. The seedling stock is not to be recommended because of uncertainty. For general use, as with western yellow pine, 1–1 is the best, both because of consistent good results and because of greater economy in raising; but 1–1–1 should be be used for very dry sites.

In large-scale plantations on the Shasta National Forest three size classes within the 1–2 age class were distinguishable, similar to those for western yellow pine. (Table 36.) Small, weak plants show distinctly lower survival than the medium and large plants. The latter, probably because of the very large top and markedly weak lateral root system, are inferior to the medium stock. The small transplants are generally those that were transplanted as inferior seedlings.

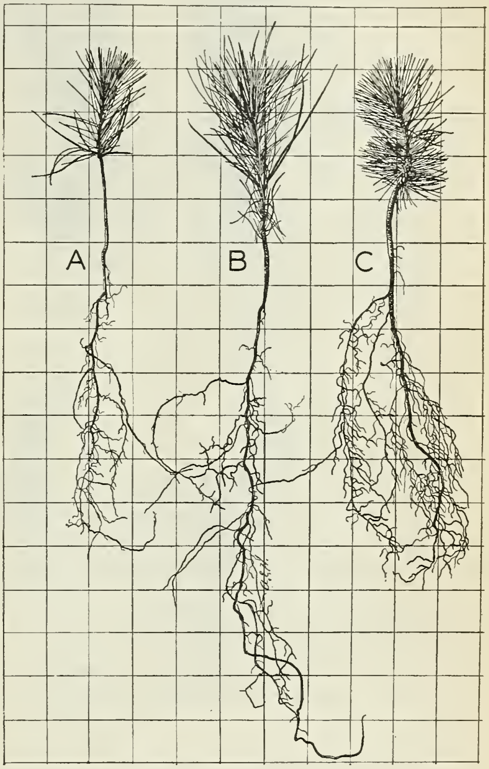

FIGURE 14.—Typical Jeffrey pine stock: A, 1–0; B, 2–0; C, 1–1. Ground lines form 1-inch squares

SUGAR PINE

Sugar pine stock of three age classes, raised at the field station and employed in field tests during one season (Table 35), developed favorable top-root ratios in the order 2–1, 1½–1, and 3–0. Survival was very low, because of the combination of a very dry season (1917) and a dry site. The order of survival, however, is that indicated by the ratios.

DOUGLAS FIR

Douglas fir seedlings 1 year old are so small as to render transplanting difficult. Moreover, the loss by death has been 52 per cent of the number transplanted, compared to 7 to 11 per cent for 2-year seedlings. For this reason alone, 2–1 stock is cheaper to raise than

1–2. The 2–1 stock also has a distinctly better ratio. (Table 35.) Because of planting on a dry site in a very dry season, survival was exceedingly low. Even so, the indications of the top-root ratio were verified in the survival.

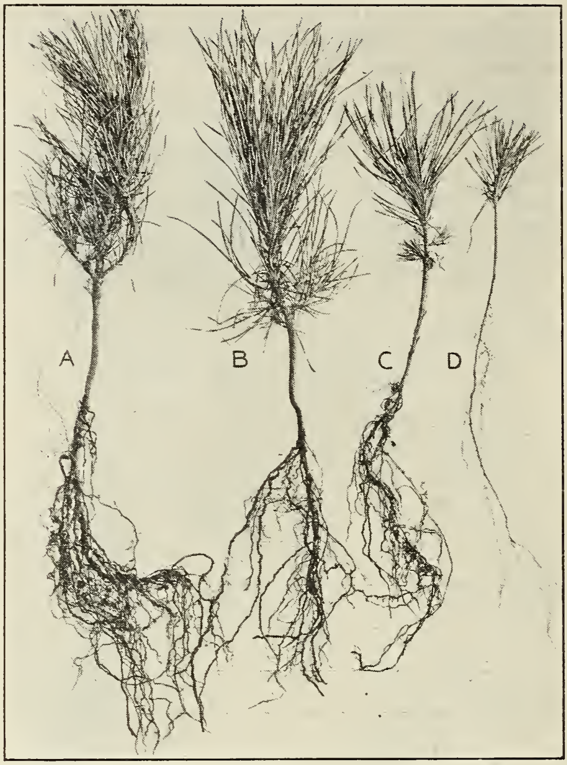

FIGURE 15.—Typical Jeffrey pine stock: A, 1–1–1; B, 1–2; C, 2–1; D, 1–0. Ground lines form 1-inch squares

WHITE FIR

White fir 1-year seedlings are too small for transplanting, the loss being 64 per cent as compared to 10 per cent for 2-year plants. Moreover, 2–1 stock had a lower ratio than 1–2 stock (2.09 as against 2.56), and a 5 per cent survival on a dry site compared to complete loss for the other age class.

INCENSE CEDAR

Duplicate tests of incense cedar paralleled those for western yellow and Jeffrey pine. Figures 16 and 17 show that incense cedar, differing from the pines, has no pronounced tendency to form a heavy taproot. There is little difference among the seedlings except in size. Among all the transplants tested the superior development of 1–1–1 stock and the very good condition of 2–1 stock was evident. The top of 1–2 was rather too large; between 1½–1 and 1–1 there was not much difference except that the 1–1 stock had a smaller top. In all classes incense cedar develops excellent fibrous root systems.

The ratios for seedlings, as shown by the 1915 tests (Table 35), are practically identical, the only difference being in the total weight, which varies directly with age. It is, therefore, to be expected that survival will be in order of age. Of the transplants, 1–1 has a lower ratio but also lower weight than 1½–1; the ratios of 2–1 and 1–1–1 are rather close but the 1–1–1 stock is the heavier. The 1–2 stock is heaviest of all, but has much too high a ratio. Although survival does not correspond in each case to ratio, the best stock with the lowest ratio (1–1–1) maintains the highest survival.

All lots of seedlings suffered heavy loss the second year in the field, and as a group average far poorer survival than the transplants. It is safe to say that under the difficult conditions in this region, incense cedar seedlings can rarely be used for field planting.

The results of the 1916 series of tests place the ratio of the 1–1 stock so far out of line that an error in weighing is probably indicated. Unlike the pines, 1–2 incense cedar gives very good results. The 2–1 stock also shows up well. No very marked advantage is gained by double transplanting, for incense cedar has little tendency to develop a heavy taproot.

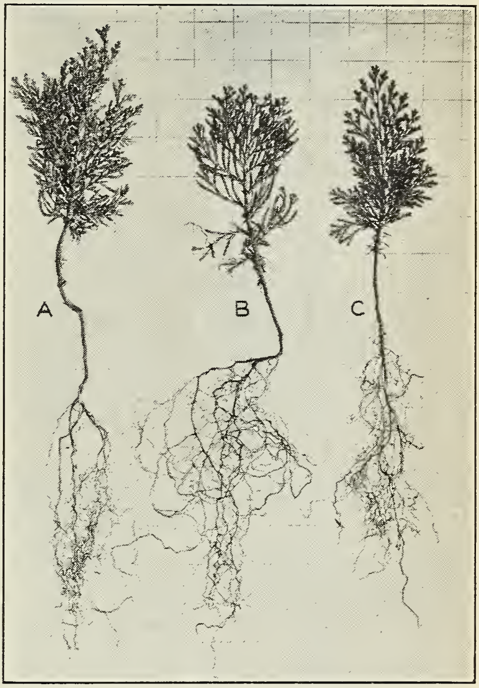

FIGURE 16.—Typical incense cedar stock: A, 1–2; B, 2–1; C, 1–1. Ground lines form 1-inch squares

SUMMARY

The most suitable age class is determined (1) by the rapidity of juvenile growth, and (2) by the characteristics of root development. Slow-growing species which do not tend to form a heavy taproot (Douglas and white firs) can best be left two years in the seed bed. Rapidly growing species, with pronounced tendency to form a taproot (such as western yellow and Jeffrey pines), must be moved every year.

If extra large or extra strong stock of the slow-growing group is required, an additional year in the transplant bed appears to be the proper treatment. With the deep-rooting species these qualities can best be obtained by a second transplanting.

Incense cedar, which grows with moderate rapidity but does not tend to form a taproot, does best if moved annually, though two years in one place also gives satisfactory results.

CHOICE OF SITE

Study of sites suitable for planting, and of the adaptability of different species is obviously an enormous field. Data collected over a period of 10 years, far from complete, indicate only some of the broader and more important angles of the problem.

If it were possible to start all plantations on bare ground, the essentials of a definition of site would be reduced to the fitness of the soil for forest trees, amount and distribution of rainfall, temperature, and other climatic factors. In brush-field planting, however, which constitutes the principal problem in California, but little experience is required to prove that the success or failure of a plantation may depend more on the character and amount of cover than on soil characteristics and climate.

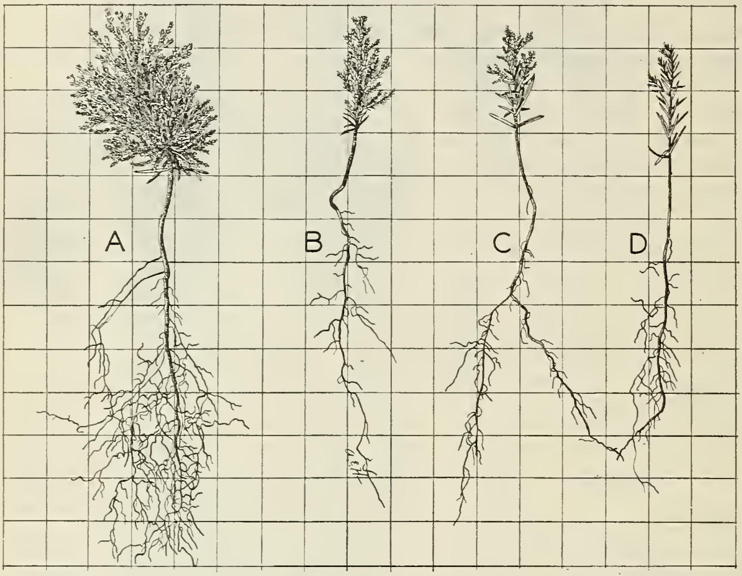

FIGURE 17.—Typical incense cedar stock: A, 1–1; B, 2–0; C, 1½–0; D, 1–0. Ground lines form 1-inch squares

INFLUENCE OF COVER

Brush cover, as an impediment to the survival of young trees, makes itself felt by the shade it casts, and because it is a heavy user of soil moisture.

EFFECT OF SHADING ON SURVIVAL

Studies in the Shasta plantations have isolated the shade factor in old brush fields and in recently burned but resprouting brush.

TABLE 37.—*Effect of shade on survival of 1–2 western yellow pine on 2-year-old burn* [1]

Degree of shade	Living plants				Dead plants
	Healthy	Sickly	Dying	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No shade	41.7	9.4	11.5	62.6	37.4
From one side	53.7	5.2	5.2	64.1	35.9
From two sides	59.7	6.8	3.8	70.3	29.7
From three sides	60.0	4.7	5.7	70.4	29.6
From four sides	64.4	3.4	4.0	71.8	28.2
Full shade	65.6	7.1	5.1	77.8	22.2

[1] Sisson burn, planting fall of 1913 basis, 1,000 plants.

Table 37, showing the effect of shade on the survival of 1–2 western yellow pine planted on a 2-year-old brush burn, where the brush had sprouted vigorously after the fire, indicates clearly that survival increases with increase in the amount of shade.

Table 38, giving similar data for plantations of pine on a burn where two qualities of site obtained, makes it clear that, other things being equal, the better the site the less is the need of shade. On the better site twice as many plants in the open lived as on the other, and the survival under partial shade was greater than with full shade on the poor site. On the good site the survival under partial shade was greater by only 20 per cent than in the open, while on the poor site it was greater by 31 per cent. The conclusion is that, other things being equal, shade is more essential and has greater effect on the poorer sites.

TABLE 38.—*Effect of shade on survival of 1–1 western yellow pine as influenced by the quality of the site* [1]

Degree of shade	Survival on—			
	Good site		Inferior site	
	Alive	Dead	Alive	Dead
	Per cent	*Per cent*	*Per cent*	*Per cent*
No shade	45.0	55.0	24.3	75.7
Partial shade	64.6	35.4	55.2	44.8
Full shade	100.0	.0	61.6	38.4

[1] "Section 30" burn. Basis on good site, 214 plants; on poor site, 164 plants. Burned August, 1910 planted fall, 1911.

Table 39 presents data from fall and spring plantations of western yellow pine on a 1-year-old burn, with an exceptionally favorable year (1913) following planting. Survival under shade and in the open is very nearly equal, and the conclusion is clear that in a favorable year shade is unnecessary for western yellow pine. Table 37, which is for the same general area, indicates correlatively that in a dry year shade is necessary even for the older age classes.

TABLE 39.—*Effect of shade on survival of western yellow pine on 1-year-old burn in a favorable year*

1-1 STOCK PLANTED IN FALL OF 1912 [1]

Degree of shade	Living plants				Dead plants
	Healthy	Sickly	Dying	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No shade	75.0	.0	1.0	76.0	24.0
Partial shade	79.0	.0	.0	79.0	21.0
Full shade	67.0	1.0	.0	68.0	32.0
Average	73.7	.3	.3	74.3	25.7

1-2 STOCK PLANTED IN SPRING OF 1913 [2]

Degree of shade	Healthy	Sickly	Dying	Total	Dead plants
No shade	76.2	0.6	.0	76.8	23.2
Partial shade	67.8	3.2	.6	71.6	28.4
Average [3]	72.0	1.9	.3	74.2	25.8

[1] Sisson burn, 3 years after planting; basis, 300 plants.
[2] Sisson burn, 2 years after planting; basis, 200 plants.
[3] No 1–2 stock under full shade.

TABLE 40.—*Effect of shade on survival of 1–1 sugar pine on 1-year-old burn, favorable year* [1]

Degree of shade	Living plants				Dead plants
	Healthy	Sickly	Dying	Total	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No shade	31.2	1.5	0.0	32.7	67.3
Partial shade	52.3	.5	.0	52.8	47.2
Full shade	85.7	.0	.5	86.2	13.8
Average	56.4	.7	.2	57.2	42.8

[1] Sisson burn, 2 years after planting in the fall of 1912; basis, 100 trees.

Different species respond differently to shade. In Table 40 are given the data on a sugar pine plantation established at the same time as the western yellow pine plot summarized in the first section of Table 39. In comparing the two it is evident that shade which had no effect on the less moisture-loving western yellow pine was a decided advantage to the sugar pine. In other words, the more drought resistant the species, the less is the need of shade. An extreme case is that of the bigtree, *Sequoia washingtoniana*, for which shade is essential. (Table 41.)

TABLE 41.—*Effect of shade on the survival of 1–2 bigtrees* [1]

Degree of shade	Plants alive	Plants dead
	Per cent	*Per cent*
Open	0	100
Partial	16	84
Full	68	32

[1] Sisson burn, planted in the spring of 1913; basis, 100 plants.

Next may be considered the relation between quality of stock and need for shade. In a western yellow pine plantation in heavy unburned brush (Table 42) the plants were classed as large, medium, and small, depending on size of top, which incidentally was correlated with size of roots. Since they were of the same age, the larger plants were the more vigorous. Although the larger plants did equally well under all shade conditions, the small plants showed a decided need for shade, which was also evidenced to a lesser degree by the medium class. Since percentage of survival is proportional to size, and size is an index of quality in this case, we may conclude that the better the stock the less is the need for shade.

TABLE 42.—*Effect of various degrees of shade on the survival of 2,000 1–2 western yellow pine of different sizes* [1]

Quality and quantity of stock planted		Survival, by degrees of shade					
		No shade	1 side	2 sides	3 sides	4 sides	Full shaded
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Large	473	40.0	49.5	43.0	45.0	45.0	45.0
Medium	1,177	16.5	25.0	26.0	31.0	35.0	35.5
Small	350	.0	9.0	13.0	16.0	22.0	27.0
Total or average		19.2	28.0	27.7	31.7	35.1	36.3

[1] Planted in the spring of 1916.

This method does not give a quantitative measure of the shade itself, but only of its effect on survival. In the brush field planted in 1916 there are two principal brush species—manzanita (*Arctostaphylos patula*), with rather an open crown; and snow brush (*Ceanothus velutinus*), with dense crown. The data in Table 43 give an interesting basis of comparison for the different degrees of shade of these species.

TABLE 43.—*Effect of various degrees of shade on survival of 1–2 western yellow pine under open-crown brush, as compared with dense-crown brush* [1]

Species of cover	Survival by degree of shade				
	1 side	2 sides	3 sides	4 sides	Full
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Manzanita	49	56	60	67	70
Snow brush	55	60	68	78	78

[1] Planting and shade measurements, spring of 1916; basis, 2,000 plants.

Snow-brush shade from 3 sides is equal in effect to manzanita from 4 sides; snow-brush shade from 2 sides is equal to manzanita from 3 sides; and snow brush on 1 side is equal to manzanita on 2 sides. The effect of full shade of snow brush, representing extremely dense brush, is, however, no greater than that from 4 sides representing moderately dense brush, and offers no greater aid.

EFFECT OF SHADE ON QUALITY OF PLANTING

In following up the 1916 plantations, which were in a dense brush field, it was found that the amount of poor planting varied strikingly with the density of the brush. That is, the greater the physical obstacles the less likely is the average worker to do a good job in setting the plant. (Table 44.) With shade from four sides and full shade, the percentage of loss from poor planting was above the average; in the more open brush it was below. The effect of species of brush on the success of planting is also interesting to observe. The data used in Table 45 were obtained by recording the species of brush (snow brush, manzanita, golden chinquapin (*Castanopsis chrysophylla*) forming the cover over each plant examined. Where more than one species occurred, the cover was classified as mixed.

TABLE 44.—*Effect of density of cover on character of work in planting*

Degree of shade	Stock planted	Losses from poor planting		
	Number	*Number*	*Per cent*	*Per cent* [1]
No shade	46	4	8.7	7.5
1 side shaded	79	5	6.3	
2 sides shaded	166	20	12.0	11.8
3 sides shaded	225	26	11.6	
4 sides shaded	617	87	14.1	13.9
Full shade	864	118	13.7	
Total and average	1,997	260	13.0	----------

[1] The percentages in this column are in each case averages of two percentages in next to last column.

TABLE 45.—*Effect of species of brush on character of work in planting* [1]

Brush species	Stock planted	Losses from poor planting	
	Number	*Number*	*Per cent*
Manzanita, open crown	406	34	8.4
Snow brush, dense crown	816	140	17.2
Chinquapin, very dense crown	64	15	23.4
Mixed	654	67	10.2
Not recorded	60	4	6.7
Total and average	2,000	260	13.0

[1] Planting and determination of shade, spring of 1916.

Under manzanita the loss is but 8.4 per cent, while under snow brush the loss is twice, and under golden chinquapin nearly three times as great. Under mixed cover, which usually has some manzanita, the loss is less than the average. Undoubtedly the heavy mulch under snow brush, and the numerous root suckers put out by chinquapin, are in part responsible for this striking difference. The heavy mulch makes it difficult to get clean soil with which to refill the holes, and consequently the plants are often poorly set, with dry mulch around the roots The root suckers make it difficult to get a clean hole, and the stiff roots projecting into the hole tend to prevent the refilled earth from reaching the roots of the plant.

In planting recently burned brush fields, where the difficulty of travel is greatly reduced and adequate supervision is easy, the loss from poor planting has run from 1 to 3 per cent. In the heavy unburned brush, with a thick layer of leaf mulch often 4 to 6 inches deep, it is sometimes difficult to get the holes deep into mineral soil, and the planter frequently fills the holes with mulch mixed with a little earth. The effect on the plant is easy to foretell.

EFFECT OF SHADE ON HEIGHT GROWTH

In 1918 measurements of total height of western yellow pine plants set out in the spring of 1912 showed a striking relation between degree of shade and height, as shown in Table 46. Because this plantation was in a recent burn, the absolute amount of shade is less than for corresponding ratings in unburned brush fields. With practically complete shade, which is probably influential in reducing transpiration, the total height is twice as great as in the open, a rather surprising difference. Although these results are plainly attributable to degree of shade, it is obvious that shade may be influential in several ways. In a brush field undisturbed by fire for many years the roots of the brush have penetrated practically every cubic inch of the top foot of soil, even in the open spots, so that the drain on the available moisture by the brush is equally operative under all conditions of shade. The reduced transpiration of the trees under shade, then, appears to be reflected in their higher survival and superior growth.

Table 46.—*Relation between degrees of shade and height for western yellow pine*

Degree of shade	Average height	Plants measured
	Feet	*Number*
No shade	0.82	63
1 side shaded	1.05	65
2 sides shaded	1.32	69
3 sides shaded	1.49	37
4 sides shaded	1.61	38
Full shade	1.63	34
Average and total	1.32	306

COMPARATIVE SURVIVAL IN BURNED AND UNBURNED BRUSH

In comparing results in burned and unburned brush of the same type, it was found that, though shade is greater in the unburned, survival is highest in the recently burned. Thus, in the 1918 plantations, western yellow pine had at the end of two years 65.6 per cent survival in burned and 54 per cent in unburned brush—the two areas, on opposite sides of a fire trail, having been planted at the same time. Soil moisture in early September, before the fall rains had come, determined for the top foot of soil, was 7.2 per cent in unburned brush and 12.3 per cent in burned. So in spite of presumably greater evaporation from the soil in the more exposed burn, the much higher transpiration of the old brush stand resulted in a strikingly lower soil-moisture content. The plants in the burn grew 1 to 4 inches in height, whereas only part of those in green brush made any growth.

RELATION OF BRUSH COVER TO RODENT DAMAGE

Nipping of the top of planted trees by various rodents has proved a serious source of loss, but planting on large burns less than two years after the fire has been successful in discouraging these attacks. On the Sisson burn of September, 1911, which was planted both in the fall of 1912 and in the spring of 1913, no rodent damage occurred. The plantations made in the fall of 1913, however, suffered severly, as Table 47 shows. Additional nipping occurred the next year, but this was confined to plants already nipped and seldom resulted in death.

Table 47.—*Rodent damage to various classes of stock planted two years after burn* [1]

Species	Age class	Nipped first year
		Per cent
Western yellow pine	1-2	11
	2-1	25
	1-1	56
	1½-1	56
Sugar pine	1½-1	15
	2-1	6
	1-2	17
Big tree	1-2	0
Jeffrey pine	1-1	70

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[1] Planted in the fall of 1913, following burn (Sisson) in 1911.

The general situation on the burn appears to be this: The fire undoubtedly kills or drives out most of the rodents on the burned area and destroys the food supply. For the first year after the fire there is no inducement for the rodents to return. But as the brush sprouts, flowers, and fruits, and as various annuals and perennials become established, the rodents gradually migrate into the area, until within three years after the fire it is entirely occupied. A study of rodent damage during 1914 indicated very strongly that the above is true. The first plants to be nipped were those nearest the unburned brush, and the heaviest spring damage was there. As the season advanced, the rodents, as indicated by their work, crept farther and farther out into the burn, and by the end of the year had completely occupied the territory.

Planting on small burns surrounded by green brush does not, therefore, eliminate rodent danger. A small burn of August, 1911, planted both that fall and the next spring, suffered heavy damage. Apparently the rodents worked out into the area much as if it had been unburned.

Age class may also be important, for in a given series of tests (Table 47) the younger age classes of each species (1–1 and 1½–1) in nearly all instances suffered more serious rodent damage than did the older classes (2–1 and 1–2). A probable explanation is that the older plants have more woody material in the stem and are, therefore, presumably less attractive to the rodents.

SUMMARY

Thus, in brush-field planting it may be concluded that for all species tested in average seasons, survival increases with increase in the amount of shade received by the plants. For western yellow pine, survival under full shade in brush is from 50 to 100 per cent greater than under no shade. After six years in the field, western yellow pine planted under shade in brush was just twice as high as that set out at the same time in openings in the brush.

On poor sites for all species the need for shade is greater than on good sites. Although the absolute percentage of survival is less on poor sites than on good sites, the percentage alive under shade on poor sites proved to be 2.5 times as high as in the open, while on good sites it was only 2.2 times as high.

Shade is unnecessary for hardy species such as western yellow pine in a favorable year (a year with precipitation well distributed during the growing season). Exacting species, such as sugar pine, have a greater need for shade than the hardy species. Even in favorable years sugar pine attained 2.7 times as high a survival percentage under shade as in the open, and in dry years the difference was greater. Very exacting species, such as the big tree, show no survival in the open, very little under partial shade, and up to 68 per cent under full shade.

The better the stock the less is the need for shade for any given species, whether different age classes are compared, or quality classes within an age class of stock.

Stock planted under species of brush with dense crowns, such as snow brush, showed higher survival than under brush with open crowns, such as manzanita; but in brush-field planting the denser the brush the higher may be the percentage of loss due to poor planting. This loss from poor planting of stock was twice as great under snow brush as under manzanita.

As between recently burned and unburned brush fields, it was found that survival was from 20 to 25 per cent higher in the burned fields, owing to better planting and to higher moisture content of the soil at critical periods. Also rodent damage was practically eliminated by early planting in extensive brush burns, but proved to be a source of serious loss in later plantings and in unburned brush.

INFLUENCE OF SLOPE, BOTH BURNED AND UNBURNED, ON SURVIVAL

Experiments were begun at Feather River in the spring of 1918 to compare plantings on various slopes in burned and unburned cut-over areas. Fifty plants each of western yellow, Jeffrey, and sugar pine, and of incense cedar were set out under nine different sets of conditions, as follows: Cut-over areas heavily burned (broadcast) two years before planting on north, south, east, and west slopes; cut-over areas unburned on north, south, east, and west slopes, and a flat. These areas were all at practically the same elevation, all (except for the flat) at practically the same degree of slope, and soil types and wilting coefficients were as nearly identical as could be expected; also all grading and planting of the stock was done by one man.

Considering first (Table 48) the plots on the burned areas and averaging all species, the relative survival of the other areas (north being 100) are: South 64, east 86, west 75. For unburned: South 67, east 89, west 32, flat 80, the value for west slope being obviously out of line.

TABLE 48.—*Summary of survival after three years in field on different slopes burned and unburned*

Species	North slope		South slope		East slope		West slope		Flat unburned	Average burned	Average unburned	Average, all sites	Relative values, all sites
	Burned	Unburned	Burned	Unburned	Burned	Unburned	Burned	Unburned					
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Western yellow pine	80	82	52	58	64	74	58	26	76	64	63	63	93
Jeffrey pine	86	81	68	48	79	76	73	34	70	76	62	68	100
Sugar pine	37	22	10	14	24	12	16	2	12	22	12	17	25
Incense cedar	51	80	34	56	54	74	44	22	54	46	57	52	76
Average	64	66	41	44	55	59	48	21	53	52	49	50	74
Relative survival:													
Burned	100	------	64	------	86	------	75	------	------	81	------	------	------
Unburned	------	100	------	67	------	89	------	32	80	------	74	------	------

Survival varies with aspect in a manner to be expected, north favoring highest values, south the lowest, and east higher than west. There is every reason to believe that the values given above are representative, for with a single exception the two tests give practically identical figures. The value of such information in general planting work is obvious.

In line with the tests cited in the discussion of influence of cover, the average survival of all species was slightly higher on the unburned area than on the burned area on all slopes save the doubtful west slope. The results on the west slope unburned are for some unknown reason away out of line. On the north, south, and east aspects, western yellow pine and incense cedar uniformly show higher survival on unburned than on burned surfaces, Jeffrey pine the reverse, and sugar pine a tendency to better results on the burned surface. In general, there appear to be slight differences in survival attributable to cover alone. The amount of brush and herbaceous stuff present on the unburned area has had no influence one way or another on the plantations.

Of the four species involved in the tests, three (western yellow pine, Jeffrey pine, and incense cedar) have come to be regarded as hardy, and one (sugar pine) as an exacting species. For the purpose of comparing survival under different conditions, average survival for each species has been computed (Table 49), with the north slope figured as 100 and all other aspects referenced to that. The figures for the three hardy species compare very closely, slope by slope, averaging 79 per cent of the survival on the north. The sugar pine, on the other hand, runs away below other species in relative survival on the south, east, and west slopes and flat, averaging but 42 per cent of the north-slope figure. Specific data on Douglas fir and white fir, both of which are exacting species, are lacking, but other work indicates that, as with sugar pine, success with them could be expected only on north slopes.

TABLE 49.—*Absolute survival and relative survival of various species on different slopes, both burned and unburned*

ABSOLUTE SURVIVAL

Species	North slope	South slope	East slope	West slope	Flat	All
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Western yellow pine	81	55	69	42	76	63
Jeffrey pine	84	58	78	54	70	68
Sugar pine	30	12	18	9	12	17
Incense cedar	66	45	64	33	54	52
Average	65	42	57	34	53	50

RELATIVE SURVIVAL[1]

Species	North slope	South slope	East slope	West slope	Flat	All
Western yellow pine	100	68	85	52	94	78
Jeffrey pine	100	69	93	64	83	81
Sugar pine	100	40	60	30	40	57
Incense cedar	100	68	97	50	82	79
Average	100	65	88	52	82	77

[1] The averages in the last column do not include figures from the north slope.

For the conditions represented by this experiment (western yellow pine verging into mixed conifer type) the column in Table 49 giving absolute survival for all aspects indicates about what may be expected. Yellow and Jeffrey pines lead the list, while sugar pine in absolute survival is only 26 per cent as high as these two hardy pines.

Although the field station was temporarily abandoned in 1917, it was possible to make arrangements to run a series of porous-cup atmometers in connection with this study during most of the growing season of 1918. One cup was placed in the center of the plantation on each of the five unburned areas (north, south, east, west slopes, and flat). The bottom of the cup was 4 inches above the ground.

Both by periods and for the season (Table 50) the evaporation varied between slopes much as would be expected. The relative seasonal values indicate that evaporation on the north slope is 77 per cent of that on the south, which is surprisingly close. Work by E. N. Munns and others indicates a general difference in evaporation of over 30 per cent between north and south slopes.

TABLE 50.—*Evaporation on different slopes in cubic centimeters per day* [1]

Period	North slope	South slope	East slope	West slope	Flat	Average
June 2 to 30	45.9	58.0	49.7	54.5	54.9	52.6
July 1 to 29	49.5	61.9	52.6	54.9	58.4	55.5
July 30 to Aug. 26	47.5	60.0	49.3	56.4	56.9	54.0
Aug. 27 to Sept. 30	26.6	37.5	30.3	36.4	36.8	33.5
Oct. 1 to 9	8.9	15.7	11.2	14.4	15.2	13.1
Average	39.3	50.9	42.4	47.3	48.5	45.7
Relative value	77.2	100.0	83.3	92.9	95.3	89.8

[1] Readings from porous-cup atmometers, Feather River, 1918.

The next question is whether under the conditions of the experiment there is a dependable relation between survival of stock and evaporation, or, in other words, whether evaporation data have any practical value as an index of what will happen on an area.

The data necessary for this comparison are brought together in Table 51. Line 1 gives relative survival on different aspects as in Table 49, except that the values for the unburned west slope have been disregarded as being clearly out of line. Line 2 gives relative evaporation as in Table 50. Line 3 converts evaporation into figures varying in the same direction as survival. Obviously the higher the evaporation the lower the survival, and the device of computing reciprocals for actual evaporation is necessary to compare directly the two factors of evaporation and survival. Line 4 then gives the relation between lines 3 and 1, and is simply a set of index figures expressing the relation to be studied.

TABLE 51.—*Index of relation between evaporation and survival*

Data	North	South	East	West	Flat	Average
Survival	100	65	88	74	82	77
Evaporation	77	100	83	93	95	90
$\frac{1}{\text{Evaporation}}$	1.30	1.00	1.20	1.08	1.05	1.11
Index	.77	.65	.73	.69	.78	.69

It appears that, except for the south slope, survival is practically a direct function of total evaporation, the figures for the different aspects being north 0.77, south 0.65, east 0.73, west 0.69, flat 0.78. That is, within the limits of the experiment, the amount of evaporation under different conditions is an indirect but accurate expression of the average survival to be expected. Accordingly, aspect is reflected in plantation results to the extent that it definitely influences evaporation.

The reason for the lower survival per unit of evaporation on south as compared to other slopes can not be definitely assigned. It is possible that under the conditions of the experiment the rate of evaporation reached on the south slope was greater than what may be conceived to be the critical point. Up to a certain rate, loss in plantations will vary directly as evaporation; beyond that an increase in evaporation will result in a disproportionately high loss of plants.

White and Douglas firs have been planted under the conditions obtaining on the unburned flat used in this experiment with almost complete failure—results very close to those observed with sugar pine. Both species planted on north and east slopes contiguous to the areas used in this study attained survivals as high as 75 per cent. The temporary abandonment of the station made it impossible to carry the study for the firs to a conclusion, but the evidence indicates that they will react in about the same manner as sugar pine.

On exacting sites, the results of the study, as well as administrative experience, show clearly that western yellow and Jeffrey pines are the desirable species, and that sugar pine and probably the firs should be used only on the cooler, more favorable sites.

SOIL TYPES

But few specific data are available regarding the effect of type of soil on the establishment of different species. The subject is such a large one that it can not be solved without a deal of specific and detailed work. However, a few points worthy of note may be brought out.

In the Shasta work repeated efforts to establish sugar pine on the so-called lava-ash soils of the McCloud area resulted in almost universal failure. This is a very loose and porous soil on which sugar pine does not grow naturally at all; the species uniformly stops abruptly at the very line where clay or loam soils cease. Conversely, small plots in clay soils have shown high survival of sugar pine. Jeffrey and western yellow pines and cedar have done equally well on all the soil types so far tried. The small amount of work done with white and Douglas firs is insufficient to justify any statement regarding their response on the various important soils.

PLANTING ON NONTIMBERED LANDS

Various attempts were made to establish forests by planting on nonforest lands; that is, those on which there is now little or no direct evidence that forests once existed. Two principal types of land were used—the chaparral of the western Sierra foothills, and the deserts within the western yellow pine type of the east slope.

Plantings in the chaparral were uniformly a failure. Conditions encountered were severe—thin soil, drying out early in summer, high temperature, and competition from established cover.

The plantings on east-side deserts were made after the competing brush species—sage, bitter brush, and rabbit brush—had been destroyed by fire. These species do not sprout, and therefore, the only competition afforded was that of grass. On such areas success was attained with both western yellow and Jeffrey pines, the survival exceeding that on comparable plantations in near-by brush fields. On the other hand, plantings on deserts where brush had not been destroyed were generally failures.

Eradication of chamise (Adenostoma) by fire is impossible in the chaparral, because of its vigorous sprouting. Any attempts to afforest such lands in their present condition (i. e., without waiting for soil building) can hope for success only if the brush is previously removed, root and branch.

PLANTING ON RECENTLY DEVASTATED FOREST LANDS

Plantings have been few on lands from which the forest has been swept by lumbering and fire and on which no brush cover was present nor had become established following the devastation. The few attempts have been generally successful, however, survival as high as 85 per cent at the end of the first season having been attained. Lands of this character are probably the easiest to plant. Physical obstacles are practically eliminated, and root competition is slight. However, much additional work is required to solve the problem in all its phases.

METHOD OF PLANTING

Parallel tests of several planting methods, made by one man in a recently burned brush field, showed that 100 plants could be set in 56 minutes by the center-hole method (*6*), in 54 minutes by the side-hole method, and in 34 minutes by the single-stroke method. Survival at the end of the first season was practically identical for all lots. In medium dense brush 115 minutes were required to set 100 plants by the side-hole method, and survival was 15 per cent lower than on the burn.

SUMMARY

The character and amount of cover is of paramount importance in deciding on sites to plant. Survival is higher in recently burned than in unburned brush fields. It is still higher on deserts from which competing brush cover has been removed.

Attempts to introduce sugar pine and Douglas fir on soils on which these species do not naturally grow have generally been failures.

Attempts to plant sugar pine, Douglas fir, and white fir on denuded areas within the pure western yellow pine type, even on suitable soils, have likewise failed.

CAUSES OF LOSS IN BRUSH-FIELD PLANTATIONS

The major causes of loss operative during the first year of a plantation are careless handling, poor planting, rodent damage, and drought.

CARELESS HANDLING

Loss from careless handling includes drying out in the nursery during lifting and packing, poor packing in the crates, exposure of the crates in the field, and exposure of the plants while carried by the planter. These items can not be segregated after the plants are set out, for the only diagnostic character of careless handling is the wilting or death of the plants soon after planting.

In an extreme instance, in the course of administrative planting loss was very high from this source, as shown in Table 52. All species were handled in the same manner, and therefore the comparative losses are of some value in indicating the ability of each species to endure mistreatment. Western yellow and Jeffrey pines are least susceptible, while sugar pine is nearly twice and cedar over three times as susceptible. The roots of cedar do not retain the thin film of soil which adheres to the roots of the pines.

TABLE 52.—*Extreme instance of loss of different species from careless handling* [1]

Species	Plants examined	Plants dead	
	Number	*Number*	*Per cent*
Western yellow pine	2,000	540	27
Jeffrey pine	500	120	24
Sugar pine	200	86	43
Red fir	100	35	35
Incense cedar	100	81	81

[1] Planted in spring of 1916.

Within an age class, the ability to survive careless handling varies with the vigor of the plant. Thus for yellow pine 1–2 stock the large plants showed 17.5 per cent, the medium or average plants 28.5 per cent, and the small weak plants 34.6 per cent loss from handling. On properly conducted operations this source of loss can be reduced to 1 per cent.

POOR PLANTING

On open ground, as in recently burned brush fields, supervision of planting crews is relatively simple. In practice immediate loss from poor planting can be reduced to 1 per cent. Poor planting, at least in the grosser forms, is indicated by death of the tree soon after setting out. Setting too high or too low, failure to pack soil around the roots, filling in with leaf mold, or shallow holes resulting in badly curled roots distinguish poor planting from careless handling. In dense brush loss from poor planting is much more difficult to avoid.

Perhaps in the long run the most serious losses are among trees which, although they survive the first few years in the field, yet were incorrectly set. In light soils free from rock the rapid single-stroke method of planting is not a cause of early death, and yet, elsewhere, in digging out plants which died years after planting, it is often found that those set with the roots in a single vertical plane, (as in slit planting) continue their root development in the same plane. Thus the tree gets poor mechanical support and can not utilize the available soil moisture. Whether in the long run the majority of plants thus set develop and survive is undetermined.

A common type of poor planting is setting in a shallow hole, with the lower roots curled or parallel to the ground surface. Here, too, the tendency is for the roots to develop in the direction started. Plants set with roots curled into a spiral appear to die from self-strangulation. Thus, technic of setting out plants is an enormously important factor in planting.

SEASON FOR PLANTING

Of the two seasons suitable for field planting operations—fall and spring—the results of detailed experimental work at Feather River and of administrative planting on the Shasta National Forest are of value in determining which is the better. These results are discussed by species.

WESTERN YELLOW PINE

The results of three years' parallel tests of western yellow pine at Feather River, in which several age classes were used, give spring planting a consistent superiority. Of the 26 parallel tests that were made, spring planting showed higher survival in 22, or 85 per cent. Average survival was 31.8 per cent for fall-planted stock and 38.5 per cent for spring planted. The reason for the heavier loss in fall planting is clear. The plantings were on small flats subject to extreme cold (−12° F.) in winter and great heat and drought in summer. The soil was a heavy clay which frost heaved badly. The periodic examinations showed that loss from this cause in fall plantations just equaled the difference of 7 per cent between fall and spring planting. On heavy soils, at least, fall planting should be avoided.

Rodent damage was serious in the fall plantings in brush fields, the loss in one series of tests averaging 18 per cent. Plantings in the same area the following spring lost but 4 per cent from rodents. Extensive tests covering a period of eight years confirm this apparent advantage of spring planting.

Weather is another factor making fall planting less desirable. In at least three years out of five the ground remains dry until late fall. The first precipitation is then usually snow, making planting impossible, or if rain does come the ground freezes as soon as it is moist. Fall planting, even in relatively favorable years, is an uncomfortable task and careless setting of the plants is more difficult to guard against then than in the spring.

A comparison of early, intermediate, and late spring planting made on the Shasta Forest, in 1916 gave striking results. The survival of early planted (May 1–15) western yellow pine stock, age class 1–2, was 44.7 per cent; of that planted from May 16 to 25 survival was 30.5 per cent, and of late-planted stock (May 26 to 31) but 18.2 per cent. In spring planting the plants should be set out at the earliest possible moment.

JEFFREY PINE

Detailed tests of the best season for planting Jeffrey pine resulted, as with western yellow pine, in maintaining a consistent superiority for spring planting. Of 10 parallel tests, 9 gave the superiority to spring planting. Average survivals were 43 per cent for fall and 48.5 per cent for spring plantings. The losses in the fall plantings were due mainly to frost heaving, but loss from rodents in brush-field plantings set out in the fall were also as serious as for western yellow pine.

Tests of the best period for spring planting resulted in 53 per cent survival from early spring planting of 1–2 stock, 43.4 per cent from intermediate, and 28.3 per cent from late planting. Early spring planting is clearly indicated as most desirable. In this particular area, because of snow, May 1 is the earliest possible planting date, allowing a planting season of not over three weeks.

SUGAR PINE

Of eight detailed tests of sugar pine on the experiment station grounds spring planting was ahead in all, averaging a survival four per cent greater than that from fall planting. In brush-field planting the rodent factor is even more serious than for western yellow and Jeffrey pines.

DOUGLAS FIR

Out of eight similar tests with Douglas fir, spring plots were ahead in seven tests. The average superiority of spring planting was 3 per cent. In one brush-field plantation rodents killed 45 per cent of fall-planted stock.

WHITE FIR

In six out of seven tests at Feather River, the spring-planted white fir had a higher survival than fall-planted stock, the average difference being 4 per cent. In one brush-field plantation established in the fall, the loss from rodents was 53 per cent.

INCENSE CEDAR

In similar tests with incense cedar, spring planting was superior to fall planting in six out of eight instances in one series, and in four out of six in a second series. In brush-field planting rodents destroyed 93 per cent of the fall-planted stock and but 7 per cent of the spring-planted. Survival was zero for fall and 21 per cent for spring planting.

SUMMARY

For all species planted on open ground, the soil being a heavy clay, the survival for spring plantations was from 3 to 7 per cent higher than for fall plantings. On such sites frost heaving is a cause of loss in fall plantations. In brush-field planting where soil characteristics are not a factor, rodent damage is high on fall and low on spring plantations. Planting as soon as snow leaves the ground in early spring is the most successful.

RECOMMENDATIONS FOR FUTURE WORK

Thus far research in nursery practice has solved most of the detailed questions of technic. It is now possible to produce high-quality stock of the important Sierra conifers. The problems of outstanding importance on which additional work is required deal with the effect of soil fertilizing, especially if repeated, on the quality of stock produced, and the comparative merits of different soils. It should also be determined whether a nursery at high or at low altitude is the more suitable for production of sugar pine, Douglas fir, and white fir stock. It is demonstrated that nurseries in the western yellow pine belt are not suitable for these species.

In field planting a great deal remains to be learned, in spite of a promising beginning. The early work has demonstrated the most suitable age class of each species, has indicated the best season for planting, and has thrown much light on the conditions to be met in brush-field planting. Some information has been obtained concerning the relative hardiness of the important tree species on different sites, on the possibility of planting chaparral and sagebrush land, and on the rôle of brush cover as a heavy user of soil moisture.

The continued loss in plantations 15 years old, partly attributable to poor planting, shows the necessity for further study of the technic of setting out plants. The European practice of digging natural seedlings, retaining the core of earth around the roots, and setting the plants in the desired location is worthy of careful study. This may prove one means of avoiding the after effects of careless planting. Losses such as those from the drought of 1916–1924 probably can not be avoided entirely. Even natural reproduction older than the planted stock suffered severely during this period, particularly in the culminating year of 1924.

Future work in field planting should aim to cover a wide range of soil types and site conditions. Brush-field planting remains the problem of outstanding importance. A great possibility for progress is the development of mechanical means—the tractor, for example—to eradicate the brush in advance of planting. A saving of several dollars an acre in planting cost alone may be effected in this way.

A good deal of land recently denuded of forest by logging or fire, on which a brush cover has not become established, will be acquired by the Federal Government through exchange. Planting on these lands should be studied.

To restore lands which through repeated burning and erosion bear only a chaparral cover, no known method is immediately effective. Here the first problem is one of soil building and the second of eradicating the brush cover. Among the native hardwoods such species as California black oak are known to build up the soil. Experiments should be begun in the establishment of a nurse crop of some such species, to be underplanted later with the desired conifer.

Above all, in future work, careful and detailed study should be made of all plantings, to determine not only the factors affecting initial survival, but the subsequent history and development of the trees.

LITERATURE CITED

(1) LIVINGSTON, B. E., and SHREVE, F.
1921. THE DISTRIBUTION OF VEGETATION IN THE UNITED STATES, AS RELATED TO CLIMATIC CONDITIONS. 590 p., illus. Washington, D. C. (Carnegie Inst. Wash. Pub. 284.)

(2) SHOW, S. B.
1917. EFFECT OF DEPTH OF COVERING SEED UPON THE GERMINATION AND QUALITY OF STOCK. Jour. Forestry 15: 619–623.

(3) ———
1917. METHODS OF HASTENING GERMINATION. Jour. Forestry 15: 1003–1006.

(4) ———
1926. TIMBER GROWING AND LOGGING PRACTICE IN THE CALIFORNIA PINE REGION. MEASURES NECESSARY TO KEEP FOREST LAND PRODUCTIVE AND TO PRODUCE FULL TIMBER CROPS. U. S. Dept. Agr. Bul. 1402, 76 p., illus.

(5) ——— and KOTOK, E. I.
1924. THE RÔLE OF FIRE IN THE CALIFORNIA PINE FORESTS. U. S. Dept. Agr. Bul. 1294, 80 p., illus.

(6) TILLOTSON, C. R.
1917. REFORESTATION ON THE NATIONAL FORESTS. U. S. Dept. Agr. Bul. 475, 63 p., illus.

(7) ———
1917. NURSERY PRACTICE ON THE NATIONAL FORESTS. U. S. Dept. Agr. Bul. 479, 86 p., illus.

(8) TOUMEY, J. W.
1916. SEEDING AND PLANTING; A MANUAL FOR THE GUIDANCE OF FORESTRY STUDENTS, FORESTERS, NURSERYMEN, FOREST OWNERS, AND FARMERS. 455 p., illus. New York.

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